Willingness to pay for mortality risk reduction due to air pollution: a case study from Brazil

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Willingness to pay for mortality risk reduction due to air pollution: a case study from Brazil

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Esse trabalho é dedicado a Luana de Figueiredo Ortiz.

Com todo carinho e amor para a Linda do Papai.

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Summary

Air pollution is one of the most serious environmental health risks in developing countries. Epidemiologic studies have reported significant associations between urban concentrations of air pollution and mortality. Authorities are required to formulate and implement policies that aim to improve air quality, and cost-benefit analysis can be a useful tool to evaluate the environmental–policy options. The monetary valuation of the mortality impact is an essential input to such cost-benefit analysis since the mortality effects correspond to the major component of the benefits of policies that improve air quality.

This study aims to estimate the willingness to pay (WTP) to reduce risks of death associated with 'typical' air pollution policies and the value of a statistical life (VSL) in Sao Paulo, Brazil. It uses a methodology that has previously been tested in several industrialised countries, involving a computer-based contingent valuation survey. VSL in Sao Paulo ranged between US$0.77 and US$6.1 million, while our preferable estimates for policy analysis in Brazil are US$0.77 – US$1.31 million. These numbers are higher than expected for a middle-income country like Brazil. It was identified a bias – 'yeah-saying' behaviour – and the results excluding those respondents ranged between US$0.41 and US$2.41 (preferable estimates US$0.41 – US$0.48) million.

No significant age, cancer, respiratory or cardiovascular disease effects on the WTP estimates were identified, whereas a positive effect of the physical function score was identified. WTP estimates for reduction in risk of dying in the future were consistent with theory only when individuals who inconsistently answered the WTP questions were removed. Benefit transfer, the most used alternative technique in developing countries to original valuation exercises, presented average transfer errors equal to 69%. Two case studies compared the results obtained by using benefit transfer with the results using our estimates, suggesting that benefit transfer can result in inaccurate policy analysis.

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No significant age, cancer, respiratory or cardiovascular disease effects on the WTP estimates were identified, whereas a positive effect of the physical function score was identified. WTP estimates for reduction in risk of dying in the future were consistent with theory only when individuals who inconsistently answered the WTP questions were removed. Benefit transfer, the most used alternative technique in developing countries to original valuation exercises, presented average transfer errors equal to 69%. Two case studies compared the results obtained by using benefit transfer with the results using our estimates, suggesting that benefit transfer can result in inaccurate policy analysis.

1. Introduction

Ambient air pollution represents an important environmental health risk in the developing world, in particular in urban centres. Sao Paulo, the largest Brazilian metropolis, with significant regional, industrial and economic importance has, as a consequence of its economic dynamics and its high population density, more than 10 million people living within its urban area (IBGE, 2000) and the population faces serious environmental problems. The concentration levels of air pollutants in Sao Paulo are among the highest in the world, the causes being linked to the great number of vehicles and the considerable concentration of industries. In addition, Sao Paulo presents geographic characteristics that contribute to eventual thermal inversions, which increase the accumulation of atmospheric pollutants.

The epidemiologic literature developed during the last twenty years provides strong evidence that exposure to outdoor air pollution in urban centres is positively associated with a range of acute and chronic health effects, ranging from minor effects such as physiological disturbances and eye irritation to death. In Brazil, studies associating air pollution with different health outcomes have been developed since the mid nineties; most of the studies were carried out in Sao Paulo. Some studies associated air pollution in Sao Paulo with different morbidity outcomes, for example, emergency room visits due to chronic lower respiratory diseases in the elderly and ischemic cardiovascular respiratory diseases in children, and hospital admissions due to respiratory problems in children and adolescents. Also, several studies have reported significant associations between urban concentrations of air pollution and "all-cause" mortality, cardiovascular mortality, and respiratory mortality, plus deaths due to more specific causes such as pneumonia and chronic obstructive pulmonary disease. These studies suggest that fine particulate matter (PM_{10}) is the most harmful pollutant for human health, although other pollutants such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3) have also been found to be related to health events.

In this context, the environmental authorities are constantly required to formulate and implement policies that aim to increase air quality, and consequently, to reduce the health impacts of air pollution in the exposed population. In order to evaluate such policies, cost-benefit analysis can be a useful tool in providing a means of comparison between policies and, above all, in evaluating whether the overall benefits associated with the policy are greater than its costs. Thus, the monetary evaluation of the associated health impacts of the policies is an essential input to the cost-benefit analysis of any air-quality policy assessment. In addition, the health effects are likely to correspond to the major component of the benefits of policies to improve air quality, and reductions in the risk of premature death are widely believed to be the most important benefit underlying many environmental programmes, including those related to reduction of air pollution (Krupnick *et al.*, 2002). It can be concluded that it is important to estimate in monetary terms the benefit of reducing risks of death when evaluating policies or environmental programmes that reduce air pollution.

It is important to discuss in advance eventual ethical concerns involving the process of establishing monetary values to reductions in risk of mortality and, consequently, to human lives. It is observed that reductions in risks to human lives are always related to costs incurred to achieve the risk change. For example, individuals purchase safety goods such as smoke detectors, visit a doctor or undertake clinical exams regularly, attitudes that can be associated with costs measured in terms of money and/or in terms of forgone utility. Consequently, mortality risk reductions are inevitably constrained by individuals' income, imposing upon individuals the task of choosing which risks to incur. At the social level, "...the key issue is the risk reduction that is achievable for any given expenditure and the value society places on this risk reduction" (Viscusi, 1993). In the context of risks to death associated with air pollution, in which the most important benefit associated with policy making and regulation is the reduction in probabilities of premature death among the population exposed to pollutants, it is important to estimate how much the society evaluates the small mortality risk reductions associated with these policies, and to compare with their corresponding social costs. Because these small risk reductions are associated with an expected number of premature deaths avoided in a given period of time, it is said that the society's total willingness to pay to avoid such deaths divided by the number of avoided deaths corresponds to the value of one statistical life. In summary, what is being valued is not a specific human life but small mortality risk reductions that correspond to a number of unknown lives saved, and "identifiable deaths are not the same as statistical deaths" (Keeney, 2004).

The economic problem associated with policy making on the grounds of air quality arises when it is recognised that life cannot be free of risk, and reducing one type of risk necessarily increases other mortality risks since everyone must die at some point of time. Therefore, policies aiming to reduce mortality risks may be associated with other risks or with a transfer of risks from one social group to another. In other words, effective decisions about risks require trade-offs between objectives: "the question is whether the public should pay for very expensive risk-reduction programmes that would avert a few statistical deaths but result in considerably more deaths associated with reduced income" (Keeney, 2004).

Economists evaluate changes in risks of death using two general alternative approaches: the human capital approach and the willingness-to-pay approach. The first approach estimates the economic productivity of the individual whose life is at risk by using individuals' discounted lifetime earnings as its measure of value, and assigning values in direct proportion to income. The willingness-to-pay approach assumes that the preferences of individuals can be characterised by substitutability between income and safety, that is, that individuals make trade-offs between the consumption of goods or services and the factors that increase the consumer's safety. These trade-offs reveal the values individuals place on their safety or on the reduction on their risks of death. Several economic valuation methods comprise the willingness-to-pay approach. The valuation methods are in general divided in revealed preference techniques and stated preference techniques. Revealed preference techniques are those where individuals reveal their preferences in associated markets such as the labour market ('compensating-wage' method) and the housing market (hedonic-price models). Individuals that state their preference through questionnaires simulating contingent markets (contingent valuation method) or structured games (choice experiments) characterize stated preference techniques. Each approach and valuation method has its associated characteristics, advantages and disadvantages in dealing with the evaluation of small risk reductions to life.

The methodology used in this research involved the use of a contingent valuation computer-based survey instrument developed by Krupnick *et al.* (1998) specifically to fill some gaps in the contingent valuation literature concerning the elicitation of willingness to pay for reduction in risks of death. This survey instrument was adapted to the Brazilian context and used to elicit the willingness-to-pay measure related to reductions in risk of death in Sao Paulo, Brazil.

Epidemiologic studies also suggest that the short-term mortality impact of air pollution tends to be more significant among the elderly, children, and those individuals in poor health. Thus, when analysing the benefits of policies that aim to reduce air pollution, economists should initially consider that the willingness to pay for a reduction in the risk of dying might differ between young and old individuals, and between healthy and impaired groups. Theory, however, is inconclusive about the role of age and health status in the willingness to pay for small reductions in probabilities of death and the value of a statistical life. For example, it can be initially expected that willingness to pay increases with the probability of dying during the following year (baseline risk), which increases with age. On the other hand, willingness to pay also depends on the marginal utility of future consumption, which is not clear whether and how it can be influenced by age (Alberini *et al.*, 2004b). In other words, these issues have to be tested empirically, and it remains controversial in the literature whether willingness to pay for mortality risk reduction should vary with the age and health status of individuals whose lives are extended.

Other important issues are involved in the valuation of mortality risk reductions such as the effect of altruism – the fact that individuals may be concerned not only about their own welfare but also about other individuals' welfare – and the latency period inherent to some diseases associated with air pollution (e.g. cancer). Theory predicts that the willingness to pay for a risk reduction happening in the future should be lower than the willingness to pay for an immediate risk reduction of the same size. This is because there are uncertainties about the future, both related to individuals surviving to the period they would enjoy the benefit and related to the individuals' marginal utility of future consumption. The uncertainty in this case regards how different the immediate and latent estimates should be in order to proportionate accurate policy analysis.

The objective of this research is to estimate how much individuals in Sao Paulo are willing to pay to reduce their risk of dying from diseases related to air pollution. As a consequence, to estimate for the first time in Brazil the value of a Brazilian statistical life. The research questions investigated are: (i) how does the age of the respondents affect the willingness to pay for a contemporaneous mortality risk reduction? (ii) what is the impact, if any, of the health status of the respondents? (iii) do the willingness-to-pay values for a reduction in mortality risks that happen in the future follow the economic theory's prediction? The results of this research can provide policy makers in Brazil with an important statistic for policy assessment on the grounds of air pollution, and the empirical tests of the important issues involved can contribute to the sparse literature in the field. Finally, by comparing the results of this research with related studies conducted in developed countries, it can contribute towards future research and policy evaluation in Brazil and other developing countries.

This thesis is organised as follows. Chapter 2 reviews the epidemiologic literature associating air pollution with health outcomes, providing a general overview of the main air pollutants and their links with human health; the general methods used in epidemiologic studies; and the recent Brazilian epidemiologic studies, focusing on studies relating air pollution to mortality in Sao Paulo. Chapter 3 explores the different approaches economists use to establish appropriate economic values for changes in risk of death and to estimate the value of a statistical life. It discusses the adequacy of the willingness-to-pay approach and the contingent valuation method for the purposes of this research, and the economic models that provide the theoretical basis for willingness-to-pay measures for risk reductions. Chapter 4 reviews the main empirical studies that estimate willingness to pay to reduce risks of death and the value of a statistical life, focusing on 'compensating-wage' studies, contingent valuation studies, averting behaviour studies, and meta-analyses. It discusses some issues involved in valuations of risks to life including altruism, moral and ethical issues. In addition, it introduces some alternative metrics to the value of a statistical life commonly used in medical literature (health indices) and specifically in the context of air pollution (the value of a statistical life year).

Chapter 5 introduces the empirical work undertaken in Sao Paulo, Brazil, to estimate the willingness to pay for small mortality risk reductions and the value of a statistical life. The contingent valuation survey instrument is detailed and the data analysis is reported, including the analysis of the determinants of inconsistent willingness-to-pay responses and protest responses; non-parametric and parametric willingness-to-pay values for different risk reductions; the validity tests of willingness-to-pay values; and estimates of the value of a statistical life (year). Chapter 6 discusses the research questions regarding the role of age and health statuses in the willingness-to-pay values, and the willingness to pay for a risk reduction that happens in the future. It investigates whether willingness to pay for reduced future risk of death in Sao Paulo corresponds to expectations and theory. Finally, Chapter 7 discusses the relevance of the empirical results obtained in this study in terms of policy analysis in Brazil. Alternative approaches that can provide approximations of the value of a statistical life (year) are introduced and the Brazilian studies available are reviewed. In addition, it discusses the benefit transfer procedures that are, in general, the alternative procedures adopted in developing countries in the absence of resources for undertaking original revealed and/or stated preference studies. Benefit transfer validity tests are performed to estimate potential 'errors' of benefit transfer estimates when compared with willingness-to-pay estimates generated in this study. Finally, case studies of policy analysis in Brazil are presented to explore the implications for policy analysis of using benefit transfer estimates instead of the results provided in this study. Conclusions and discussions are drawn in Chapter 8.

2. Air pollution and risk to human health

It is widely accepted that exposure to outdoor air pollution is associated with a range of acute and chronic health effects, ranging from minor disturbances such as eye irritation to death from respiratory and cardiovascular disease (HEI, 2004). The evidence of this association is based on epidemiologic studies of disease occurrence in human populations, which relate changes in exposure to air pollution in space and time to health outcomes, and also from experimental studies of animals and humans. Epidemiologic studies on the health effects of air pollution provide estimates of the health effects of both short- and long-term exposure to a variety of air pollutants in human populations in many parts of the world. These estimates have been the scientific basis for air quality regulations for some pollutants, since they apply to humans living in real world conditions.

The limitations of observational epidemiology include the difficulty of accounting for potential confounders, i.e. risk factors other than exposure to air pollution, and the difficulty of estimating the toxicity of specific components of the urban air pollution mixture. In fact, separating the effects of one pollutant from the effects of other pollutants present in the ambient atmosphere is very difficult. For example, WHO (2003) recognised that ozone, nitrogen dioxide and particulate matter are linked by complex atmospheric chemistry and that effects attributed to each of these pollutants may be influenced by the underlying toxicity of the full mixture of all air pollutants. Epidemiologic studies are also not ideal for studying the mechanisms by which exposure to air pollution produces disease (pathophysiological pathway of disease).

Among the relevant results found in the epidemiologic literature, there is evidence of a relationship between ambient air pollution and an increase in the severity or duration of an already established respiratory disease. Also, mortality has long been a key health endpoint in epidemiologic studies. It is a distinct and discrete health outcome, and mortality data are routinely collected and readily available for epidemiologic analyses (HEI, 2003).

This chapter aims to review the epidemiologic literature associating air pollution and health outcomes. The following section provides a general overview of the main air pollutants and their possible links with human health. Section 2.2 describes the methods used in epidemiologic studies, while the main issues addressed in the international epidemiologic studies are detailed in section 2.3. The recent Brazilian epidemiologic studies are described in section 2.4, focusing on studies relating air pollution to mortality in Sao Paulo.

2.1. Main air pollutants

This section describes the main air pollutants, their characteristics, possible emission sources and health impacts. It is based on a number of similar reviews of the existing evidence such as Omarsal and Ganton (1997), HEI (2003, 2004), Harrison (2004), Kojima and Lovei (2001) and WHO (2003).

- *Airborne particles - Particulate matter (TSP, PM_{10}, $PM_{2.5}$)*

According to Harrison (2004), airborne particles or particulate matter (PM) are microscopic pieces of solid material or liquid droplets, other than pure water, floating freely in the atmosphere. Various terms are used to describe particulate matter, some derived from and defined by sampling and/or analytic methods, e.g. suspended particulate matter, total suspended particulates (TSP) and black smoke. Others refer to the site of deposition in the respiratory tract, e.g. inhalable particles, which pass into the upper airways (nose and mouth), and thoracic particles, which deposit within the lower respiratory tract, and respirable particles, which penetrate to the gas-exchange region of the lungs. Other terms, such as PM_{10}, have both physiological and sampling connotations (WHO, 2003).

These particles are observed in different sizes, ranging from a few nanometres (billionths of a metre) in diameter up to about 100 μm[1] (100 millionths of a metre) (Harrison, 2004). According to Omarsal and Ganton (1997), total suspended particles are particles with an aerodynamic diameter of less than 70 μm. Particulate matter larger than 10 μm in diameter (PM_{10}) results from physical actions such as wind erosion or grinding operations and tends to settle near its emission source. Particulate matter with an aerodynamic diameter of 2.5 μm ($PM_{2.5}$) or less is defined as fine particles, while larger particulate matter is called coarse particles. Particles emitted directly from a source are named primary, while particles that are formed within the atmosphere, mainly from the chemical oxidation of atmospheric gases, are termed secondary

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[1] 1 μm = 1 micrometer = 1 micron = 10^{-6} meter.

(Kojima and Lovei, 2001). Particles greater than 10 μm in diameter are large enough to settle quickly from the atmosphere due to gravity, while particulate matter with an aerodynamic diameter of 10 μm or less remains in the atmosphere for longer – hours or even days – because of its low settling velocity. The smaller particles present the highest risk to the human health because they can penetrate deeply into the respiratory tract and cause respiratory illness (discussed below).

Because of the diversity of airborne particulate matter, there are different metrics of measurement, that is, different ways of assessing and expressing the magnitude of the pollutant load. In the past, measurements of airborne particles were made using the black smoke technique, which involves collecting particles by drawing air through a filter paper and then determining the blackening of the filter paper by the collected particles. Nowadays, the techniques used to measure particles are concerned with the particles mass rather than blackness, e.g. the use of Tapered Element Oscillating Microbalance (TEOM) instruments (Harrison, 2004).

Particulate matter originates from natural as well as anthropogenic sources. Natural sources include wind-blown soil dust, volcanic ash, forest fires, sea salt, and pollens or may be formed in the atmosphere through reactions with gaseous emissions, e.g. nitrogen and sulphur oxides react to form nitrates and sulphates respectively. Anthropogenic sources include thermal power plants, industries, commercial and residential facilities, and motor vehicles using fossil fuels (Omarsal and Ganton, 1997, HEI, 2004). The main anthropogenic source of airborne particles is incomplete combustion of fossil fuels and biomass, e.g. coal burning for cooking, heating or industrial use. The combustion of coal generates carbon as both elemental (graphitic) carbon and organic compounds absorbed on its surface. Coal also contains a substantial proportion of incombustible mineral material and trace elements, some of which enter the atmosphere with the smoke (Harrison, 2004). Road traffic is also an important source of airborne particles at ground level in urban areas. Nearly all particulate matter emitted by motor vehicles consists of fine particles and a large fraction of these particles has an aerodynamic diameter of less than 1 μm. Their small average size means that they are able to penetrate deep into the respiratory tract, especially into the alveolar regions of the lung, inducing inflammatory responses.

Various short-term and long-term epidemiologic studies published in the US and Europe have found associations of particulate matter with increased mortality (e.g. Schwartz and Dockery, 1992a and 1992b; Saldiva *et al.*, 1994) and morbidity effects such as hospital admissions, emergency room visits, time off school or work, respiratory symptoms, exacerbation of asthma, and changes in lung function (e.g. Braga *et al.*, 1999 and 2001). Recent studies have begun to strengthen the understanding of the relation between exposure to particulate matter, morbidity and mortality (e.g. Pope *et al.*, 2002). Some studies have suggested that ultra fine particles ($PM_{0.1}$), particles containing metals such as iron, and other types of particles may be the most toxic components of the air pollution mixture (HEI, 2004). According to Omarsal and Ganton (1997), particulate matter greater than 10 μm in diameter is deposited in the extra-thoracic part of the respiratory tract, while PM_{10} is deposited near the fine airways. $PM_{2.5}$ is a larger health concern because it can evade the human body's respiratory defence system and reach the lung tissue, where it can remain imbedded for years, or in the case of soluble particles, be absorbed into the bloodstream.

- *Airborne toxics (hydrocarbons)*

Hydrocarbon compounds (HC) are defined as compounds consisting of carbon and hydrogen. In air quality studies, however, the term hydrocarbon is often extended to include a variety of other volatile organic compounds (VOC) such as alcohols and aldehydes (Omarsal and Ganton, 1997). Another group of hydrocarbons of concern includes polycyclic aromatic hydrocarbons (PAH). Benzene is an aromatic volatile organic compound, which is a minor constituent of petrol. 1,3-butadiene is also a volatile organic compound, which is produced by the combustion of olefins and constitutes an important chemical in certain industrial processes, particularly the manufacture of synthetic rubber.

According to Omarsal and Ganton (1997), hydrocarbon compounds can be emitted from both natural and anthropogenic sources. Natural sources include anaerobic decomposition of plants in swamps and marshes, seepage from natural gas and oil fields, and emissions from trees. The first two sources produce methane (CH_4), and the third source produces photochemical reactive hydrocarbon compounds. Anthropogenic emission sources include motor vehicles, gasoline and solvent storage tanks and transfer stations, petroleum refineries, and chemical and petrochemical plants. Motor engines – both combusting petrol and diesel – emit toxic hydrocarbon compounds, including benzene, 1,3-butadiene, aldehydes and polycyclic aromatic hydrocarbons. They are released in vehicle exhaust gases either as unburned fuels or as combustion products, and are emitted by the evaporation of solvents and motor fuels. Benzene is present in gasoline, while aldehydes and 1,3-butadiene are not present in gasoline, diesel fuel, ethanol, or methanol, but are present in their exhaust emissions as partial combustion products. Aldehydes are also formed in the atmosphere from other mobile source pollutants and have a high photochemical reactivity in ozone formation. The major types of aldehydes formed include formaldehyde and acetaldehyde (Omarsal and Ganton, 1997).

Most hydrocarbon compounds are not directly harmful to human health at the level of concentration found in ambient air. However, through chemical reactions in the lower atmosphere (troposphere) they play an important role in forming nitrogen dioxide (NO_2) and in the photochemical formation of ozone (O_3), which are health and environmental hazards. Methane (CH_4) does not participate in these reactions. The remaining hydrocarbon compounds, non-methane hydrocarbon (NMHC), are the focus of air quality studies because they are reactive in forming secondary air pollutants (Omarsal and Ganton, 1997). Several aldehydes, such as formaldehyde and acetaldehyde, have also been designated probable human carcinogens. In addition, several of the aldehydes have been shown to induce acute respiratory effects such as shortness of breath, alteration in respiration and coughing (HEI, 2004). Other effects may include eye and nose irritation, irritation of mucous membranes and nausea. Benzene and especially 1,3-butadiene are of particular concern, as they are known to be potent human carcinogens (e.g. leukaemia). Benzene also has toxic effects that are associated with the central nervous system as well as the haematological and immunological systems. Occupational studies of exposure to high levels of benzene have found that it can damage the respiratory tract, lung tissue, and bone marrow and can cause death. Polycyclic aromatic hydrocarbons absorbed in the lungs and intestines and metabolised in the human body are carcinogenic, and associated with a 50% greater risk of bladder cancer among truck drivers and deliverymen exposed to diesel engine exhaust (Omarsal and Ganton, 1997).

- *Carbon monoxide (CO)*

Carbon monoxide is a colourless and odourless gas that is slightly denser than air. It is emitted by natural and anthropogenic sources. Anthropogenic sources form carbon monoxide from incomplete combustion of fossil fuels in motor vehicles, heating and industrial facilities, thermal power plants, and incinerators. Natural emission sources include the oxidation of hydrocarbons and other organic compounds. Conversion of carbon monoxide into carbon dioxide (CO_2) in the atmosphere is slow and takes two to five months (Omarsal and Ganton, 1997).

Carbon monoxide inhibits the capacity of blood to carry oxygen to organs such as the heart and brain, and tissues. When inhaled, it replaces oxygen in the bloodstream by binding with haemoglobin (Hb) to form carboxyhaemoglobin (COHb), which lowers the oxygen level in the blood. Because more blood is needed to supply the same amount of oxygen, the heart must work harder. People with chronic heart disease may experience chest pains when carbon monoxide levels are high. At very high levels, carbon monoxide impairs vision, manual dexterity, and learning ability and can cause death (Kojima and Lovei, 2001; Omarsal and Ganton, 1997).

- *Sulphur oxides (SOx)*

Sulphur oxides are products of the combustion of sulphur-containing fossil fuels, including solid fuels (e.g. coal), liquid fuels (e.g. gasoline, diesel, and fuel oil), and natural gas. Sulphur dioxide (SO_2), which is extremely soluble in water, is a stable, non-flammable, non-explosive, colourless and corrosive acid gas that can be detected by taste at concentrations as low as 1000 $\mu m/m^3$ or by smell at concentrations above10000 $\mu m/m^3$. It combines with water vapour in the atmosphere to produce acid rain, which is a regional air pollution problem, and to the formation of secondary particulate matter.

Thermal power generation, heating, cooking, petroleum refining, ore smelting and transportation can produce SO_2. In the atmosphere sulphur dioxide may be converted to sulphur trioxide (SO_3) by reacting with oxygen. Both react with the moisture in air to form sulphurous (H_2SO_3) and sulphuric (H_2SO_4) acids, which may be transported by winds many kilometres before falling to earth as acid rain (Omarsal and Ganton, 1997). Where significantly elevated levels of ambient sulphur dioxide are found, it is more likely to have come from the combustion of coal than from other sources. In countries where coal is rarely used, the available data suggest that ambient sulphur dioxide concentrations tend to be low (Kojima and Lovei, 2001).

Adverse health effects of sulphur dioxide include coughing, phlegm, chest discomfort, and bronchitis. Additionally, it is believed that sulphur dioxide exacerbates the effects of particulate matter, and vice versa. Sulphur dioxide has been associated with reduced lung function in asthmatics – exposure at levels as low as 0.25 ppm elicits increased bronco-constriction in people with asthma. Increased daily mortality and hospital admissions from respiratory and cardiovascular disease, even at low levels, are also associated with sulphur dioxide exposure (HEI, 2004).

- *Nitrogen oxides (NOx)*

Nitrogen oxides are formed during fossil fuel combustion processes as nitrogen in the air reacts at high temperatures with oxygen (oxidation). Nitrogen oxides include nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), dinitrogen trioxide (N_2O_3), and nitrogen pentoxide (N_2O_5). The main source of nitrogen oxides is transportation (e.g. road traffic). Other important sources are thermal power stations, heating plants and industrial processes such as waste incineration. Nitrogen oxides are also produced by natural phenomena such as lightning, volcanic eruptions, and bacterial action in the soil.

Nitrogen dioxide has a variety of environmental and health impacts. In the atmosphere, it may be involved in a series of reactions (in the presence of ultra-violet radiation) that produce photochemical smog, reducing visibility. It may also react with moisture in the air to form nitric acid (HNO_3) aerosols. In the lower atmosphere (troposphere), nitrogen dioxide forms ozone by reacting with hydrocarbon compounds. In the upper atmosphere (stratosphere) it reacts with chlorine nitrate, which releases ozone-destroying chlorine atoms upon reaction with hydrogen chloride (Omarsal and Ganton, 1997).

Nitrogen dioxide is relatively insoluble and is likely to deposit in the mucous membrane of the lower respiratory tract. The upper airways are less affected because nitrogen dioxide is not very soluble in aqueous surfaces. It has been associated with increased respiratory morbidity (e.g. asthma exacerbation and reduced lung function and rate of lung growth in children). Short-term exposure to nitrogen dioxide is associated with increased daily mortality and hospital admissions from respiratory and cardiovascular disease. Nitrogen dioxide, also an oxidant, has elicited inflammatory responses at levels as low as 1 mg/m^3 in clinical experiments and increased responsiveness to ozone and certain allergens, although other studies have reported considerably variable responsiveness to nitrogen dioxide (HEI, 2004).

- *Ozone (O_3)*

Ozone is a colourless gas that occurs in two separate layers of the atmosphere. Ozone in the outer layer of the atmosphere (stratosphere) is generated by photolysis of oxygen or naturally occurring hydrocarbon, and protects the earth from ultra-violet rays. In the lower layer (troposphere), ground-level ozone is formed by the reaction of its precursor gases, volatile organic compounds and nitrogen oxides, with ambient oxygen in the presence of sunlight and high temperatures. Ground-level ozone is a major constituent of smog in urban areas (Omarsal and Ganton, 1997). Nitrogen oxides and volatile organic compounds, the main ozone precursors, are both emitted from industrial facilities and motor vehicles, the latter being the main anthropogenic emission source. Thermal inversions increase ground-level ozone concentrations.

Adverse health effects of ozone have been observed for exposure periods as short as five minutes. Ozone has been associated with transient effects on the human respiratory system; the most significant is decreased pulmonary function in individuals taking light to heavy exercise – changes in pulmonary function have been reported for one- to three-hour exposures during exercise. Epidemiologic studies have found evidence of increased numbers of asthma attacks and hospitalisations related to increases in ambient ozone levels. Ozone may also increase the lung's reaction to allergens and other pollutants, and cause severe damage to lung tissues and impair defences against bacteria and viruses (Omarsal and Ganton, 1997). Although some recent studies have found associations of daily increases in ozone with increased mortality, evidence that long-term exposure to ozone causes chronic health effects is limited. Some evidence suggests that the lung may develop tolerance to ozone after repeated short-term exposures (HEI, 2004). It can also irritate the eyes, nose and throat, causing breathing difficulties, and provoke thoracic pain, increased mucous production, chest tightness and nausea.

- *Lead (heavy metals)*

Lead is a non-ferrous metal that has a large number of industrial applications such as the manufacture of batteries, paints, tank lining and tank piping. Motor vehicles fuelled with leaded gasoline are the main source of lead in ambient air. According to Omarsal and Ganton (1997), tetraethyl lead is added to gasoline to increase the fuel's octane number, which improves the antiknock characteristics of the fuel in spark-ignition engines. About 70 to 75 per cent of this lead is transformed into inorganic lead in vehicles' engines upon combustion and emitted to the atmosphere through the exhaust pipe along with 1 percent of the organic lead that passes through the engine unchanged. The rest of the lead remains trapped within the exhaust system. Organic lead emissions usually occur as vapour, while inorganic lead is emitted as particulate matter, often less than 1 μm in size.

The main health effects of lead exposure have been observed in children, women of reproductive age, and male adults. Newborns and children younger than 6 years old are most vulnerable – those with high levels of lead accumulated in their teeth experience lower intelligence quotients (IQ), short-term memory loss, reading and spelling underachievement, impairment of visual motor function, poor perception integration, disruptive classroom behaviour, and impaired reaction time (Omarsal and Ganton, 1997). Lead absorbed in the human body is distributed among bones, teeth, blood, and soft tissues. There is evidence that more lead is absorbed when dietary calcium intake is low, in cases of iron deficiency or diets with low levels of vitamin D and zinc. The amount of lead absorbed by the body increases significantly when the stomach is empty, and the rate of absorption is higher for children than for adults, which means that poor, malnourished children are even more susceptible to lead poisoning than other individuals (Kojima and Lovei, 2001).

2.2. The different types of epidemiologic studies

There are different sources of information about the health impacts of air pollutants. According to WHO (2003), the main sources are observational epidemiology, controlled human exposures to pollutants, animal toxicology, and in vitro mechanistic studies, each of them associated with strengths and weaknesses. Epidemiologic studies generally deal with the full spectrum of susceptibility in human populations (e.g. children, the elderly, and individuals with pre-existing diseases), and exposure occurs under real life conditions, which avoids extrapolation across species and different levels of exposure. These arguments seem to suggest that epidemiologic studies are the appropriate research method to investigate associations between air pollution exposure and different human health outcomes. "However, the exposures are complex in epidemiologic studies, unless it is a study in the workplace, inevitably includes mixtures of gases and particles" (WHO, 2003).

Epidemiologic research in general focuses on the time or space dimensions of concentrations of outdoor air pollution, but usually not both within the same population. HEI (2004) argues that short-term temporal variation (over days and weeks) in air pollution concentrations has been used to estimate effects of daily morbidity and mortality, while spatial variation in long-term mean concentrations of air pollution has been the basis for cross-sectional and cohort studies of long-term exposure. Peters and Pope (2002) state that since the late 1980s, over 150 epidemiologic studies using advanced time-series statistical modelling and related techniques have reported associations between daily changes in particulate air pollution and daily changes in respiratory and cardiovascular mortality, hospitalisations, and related health endpoints. In addition, prospective cohort studies have reported that long-term exposure to fine particulate air pollution may have impacts on cardiopulmonary mortality.

This section aims to review the different types of study design that epidemiologists have been using to investigate the potential impacts of air pollution exposure on human health. Again, it is based on a number of similar works found in the literature.

- *Time series studies*

Time-series studies have been conducted to analyse daily rates of health events such as hospital admissions or deaths in one or more areas in relation to daily concentrations of air pollutants and other risk factors that vary over months or years (HEI, 2004). Daily time-series analysis is commonly used to evaluate short-term effects of air pollution on different health outcomes. Episodes in which levels of air pollution increased to high levels and remained elevated for some period provided some of the earliest epidemiologic evidence of the health effects of short-term exposure to air pollution (e.g. Schwartz and Dockery, 1992a and 1992b).

The associations between daily health outcomes and daily concentrations of air pollutants is investigated using regression techniques to estimate a coefficient that represents the relation between exposure to pollution and the health outcome. The most usual regression method found in the literature models the logarithm of the health outcome to estimate the relative risk, that is, the proportional change in the health outcome per increment of ambient pollutant concentration. In general, analysts assume that daily health outcomes – and mainly deaths – follow a Poisson distribution, since these are considered rare events in proportion to the population investigated. Indeed, HEI (2004) states that the primary statistical approach in time-series studies has been formal modelling of count data using a Poisson regression model. If the health outcome may be influenced by seasonal changes, weather, air pollution, or other variables, then the Poisson process will be non-stationary, that is, the underlying expected mean outcome count will change over time depending on these variables. HEI (2004) concludes that Poisson regression modelling provides a formal way to evaluate possible associations between daily health outcomes, especially mortality, and daily concentrations of air pollution while controlling for other variables.

One positive characteristic of time-series studies is that individual cofactors such as smoking habit, diet, and genetic characteristics are unlikely to be confounders because they are not generally associated day to day with daily concentrations of air pollution. In fact, "such an approach is quite sensitive in detecting acute effects of air pollution on health, as the corresponding estimates are less affected by confounding variables that may be present when data obtained during large periods of time are aggregated" (Conceicao *et al.*, 2001). Recent work indicates that the magnitude of the relative risk estimates from time-series studies of daily mortality depend on the approach used to model both the temporal pattern of exposure and potential confounders that vary with time such as season and weather (HEI, 2004). In order to control for season and various potential time-dependent confounders, time-series studies of daily mortality eliminate the long-term temporal variability of exposure by using analytic approaches, such as filtering data or non-parametrically smoothing time (HEI, 2003).

Studies that use uniform methods for assembling and analysing data from multiple cities – multi-city studies – have also attempted to explain the differences among cities in relative risks associated with exposure to air pollution. For example, analysts found that the relative mortality risk of particulate matter was greater in cities with higher annual mean concentrations of nitrogen dioxide or PM_{10}. Large multi-city studies also have the statistical power to explore more precisely the shape of the air pollution concentration-response function, the timing of effects related to air pollution, and the extent of life shortening (harvesting) due to air pollution (HEI, 2004). Study designs other than the time series have also been used to study acute health effects of short-term exposure to air pollution, such as panel studies and case-crossover studies.

- *Panel studies*

HEI (2004) defines panel studies as those studies where small groups (or panels) of individuals are followed over short time intervals, during which health outcomes, exposure to air pollution, and potential confounders are obtained for each subject on one or more occasions. Panel studies have generally reported that exposure to outdoor air pollution is associated with increased upper and lower respiratory symptoms and increased rates of asthma attacks.

- *Case-crossover studies*

Case-crossover study design is characterised by the comparison of exposures of each case of health outcome in the study population among different periods near the time of the health outcome – case period – and one or more periods during which the health outcome did not occur – control periods. The relative risk is then estimated using methods for matched case-control studies, a common epidemiologic design. Ideally, control periods are chosen so that there is no need to statistically adjust for factors such as seasonality, and long-term time trends in mortality. Although case-crossover studies of air pollution are few, they seem to provide results comparable to those of standard time-series analysis (HEI, 2004).

- *Randomised (controlled) clinical trial*

Randomised clinical trial design involves random assignment of the treatment of interest between control and experimental groups of the population. It has been applied at the community level to assess the impact of health interventions such as tobacco control programs. Because randomisation leads to statistical comparability of treatment and control groups, a key strength of the randomised clinical trial is the strength of its evidence in causal inference. The randomised clinical trial provides convincing evidence for causality and accountability for comparisons for which validity is protected by the randomisation of treatment. Such experiments are considered the gold standard in biomedical research if they have sufficiently large samples, highly structured protocols, and limited variation in participation and treatments (HEI, 2003).

According to HEI (2003), even when the mechanism of action is unknown and potential confounders are not measured, causality can be inferred because randomisation increases the probability that treated and comparison groups have comparable distributions of potential confounders. However, selection bias and lack of follow up can degrade the protection afforded by randomisation and increase vulnerability to biases that affect purely observational studies, particularly if the bias is dependent on exposure and susceptibility to the health outcome. The authors conclude that randomised interventions for ambient air pollution exposures at the population level are in general not possible. Studies of people moving to areas of higher or lower pollution, cohort studies, and time-series studies have only some required features. However, randomised studies in clinical and laboratory settings can be informative (HEI, 2003).

- *Cohort studies*

In parallel with time-series studies, which focus on the short-term health impacts of pollutants, prospective cohort studies investigate the long-term effects of exposure to air pollution. According to HEI (2004), cohort studies take advantage of spatial variation in air pollution concentrations to compare incidence of disease and death in populations exposed over the long term to differing levels of air pollution. By following large populations for many years, cohort studies estimate both numbers of deaths and, more importantly, mean reductions in life span attributable to air pollution. According to Maynard (2004), some prospective cohort studies show that inhabiting a relatively polluted area for a prolonged period of time leads to a shortening of life expectancy. Two approaches have been taken to represent this health effect: (i) estimating the number of non-expected deaths occurring by a given date in a population; or (ii) estimating the total loss of life expectancy by a population that eventually dies.

Cohort studies use regression analyses that adjust for the long-term effects of potential confounders, such as cigarette smoking, occupation, and prior medical history. However, measuring actual health benefits over the long term is a challenge. For example, pollution reductions are likely to be accomplished in small increments over a long time, and other factors affecting health (e.g. medical care) are likely to change over the same time frame (HEI, 2003).

2.3. Evidence of health impacts of air pollution

A number of health effects have been associated with different air pollutants in the epidemiologic literature. For example, air pollution can worsen the condition of those with heart or lung diseases, and can aggravate asthma. In addition, air pollution is associated with a reduction in life expectancy, although the extent of this association is not fully known (COMEAP, 2001). It is understood that the severity of the effect on health is dependent on the concentration of the pollutants, the period of exposure to air pollutants and the health status of the exposed population (among other possible things). Epidemiologic studies associating air pollution with different health outcomes in the US and Europe have been developed since the air pollution disasters that happened in London in 1952, the Meuse valley in 1930 and Pennsylvania in 1948. These suggested that extremely high levels of particulate-based smog could produce increases in the daily mortality rate (Schwartz, 1994). To mention just a few examples relating particulate matter levels and mortality, Schwartz and Dockery (1992a; 1992b), Dockery and Pope (1993), and Pope *et al.* (1995) found a strong correlation between ambient particulate matter concentration and daily mortality in different North-American cities. Several other similar studies were undertaken in different regions worldwide and are summarised elsewhere (e.g. HEI, 2004; WHO, 2003), but there is still no evidence of a threshold level, beyond which no health effect is observed in humans (WHO, 2003). This section aims to review the epidemiologic literature that establishes the association between different health effects and the concentration of air pollutants, focusing on recent studies discussing relevant issues in the debate regarding air pollution and mortality events, such as harvesting[2], potential confounders and possible mortality pathways.

Pope *et al.* (2004) analysed patterns of associations between particulate matter with specific causes of death that might provide guidance toward understanding general pathophysiological pathways linking particulate matter ($PM_{2.5}$) and mortality. The authors argued that although epidemiologic observations provide compelling evidence of a link between particulate matter and cardiopulmonary morbidity and mortality, the understanding of the underlying biological mechanisms remains limited. Expected patterns of particulate matter mortality associations for specific causes of cardiopulmonary deaths were determined based on three hypothesised general pathophysiological pathways. The pathways assumed were (a) accelerated progression of chronic obstructive pulmonary disease (COPD); (b) inflammation/accelerated

[2] The harvesting hypothesis refers to the death of those individuals who were likely to die anyway in a short period of time. "This could occur if air pollution hastened the deaths of persons who were extremely frail. If air pollution did not simultaneously increase the number of people who become frail, the size of the frail pool would decrease after an air pollution episode. On subsequent days, a smaller frail pool would result in a reduction in daily deaths" (Zanobetti *et al.*, 2003).

arteriosclerosis; and (c) altered cardiac autonomic function. Specific causes of death included all cardiovascular diseases, ischemic heart disease, dysrhythmias, heart failure, cardiac arrest, hypertensive disease, other arteriosclerosis, aortic aneurysms, cerebrovascular disease, diabetes, all other cardiovascular diseases, diseases of the respiratory system, COPD and allied conditions, pneumonia and influenza, and all other respiratory diseases.

In order to test the hypothesised association pathway, Pope *et al.* (2004) analysed mortality data collected by the American Cancer Society (ACS) as part of the Cancer Prevention Study II (CPS-II), an ongoing prospective mortality study of approximately 1.2 million American adults interviewed since 1982. Participants completed a confidential questionnaire including questions about age, sex, weight, height, smoking history, alcohol use, occupational exposures, diet, education, marital status, and other characteristics. Reported deaths were verified with deaths certificates. The analysis was restricted to those participants who resided in U.S. metropolitan areas with available pollution data, resulting in three cohorts ranging from 319,000 to 500,000 individuals according to three different levels of exposure.

Pope *et al.* (2004) estimated adjusted mortality relative-risk ratios using the standard Cox proportional hazards regression model, an approach that has been used in previous studies of pollution-related mortality. The models controlled for available individual co-risk factors. To control for age, sex, and race, the models were stratified by one-year age categories, sex and race, allowing each category to have its own baseline hazard. Both indicator and continuous variables were used to control for tobacco smoking, while indicator variables were used to represent drinking habits, education and occupational exposure to asbestos, chemicals, coal or stone dust, diesel engine exhaust, and formaldehyde. Models were estimated for each of the death cause categories using each of the particulate matter indices, and in stratified analysis of smokers, former smokers, and "never smokers".

The authors found robust associations between $PM_{2.5}$ and overall cardiovascular disease mortality. Predominant particulate matter mortality associations were with ischemic heart disease, but statistically significant associations were also observed with dysrhythmias, heart failure, and cardiac arrest. Statistically significant, positive associations were not consistently observed for other cardiovascular deaths or for respiratory disease deaths. COPD and related deaths were negatively associated with fine particulate air pollution exposure. Cigarette smoking was associated with far larger excess risks for both cardiovascular and respiratory disease mortality than air pollution. For example, for "never smokers", the particulate matter mortality association with pneumonia and influenza was positive and statistically significant.

Pope *et al.* (2004) concluded that, first, although previous studies have observed that elevated exposures to particulate matter are associated with measures of lung function and prevalence of symptoms of obstructive airway disease, the pattern of particulate matter mortality associations analysed did not fit the a priori pattern presented for the accelerated progression of COPD hypothesis. Second, given the robust particulate matter association with ischemic heart disease, the empirical pattern of particulate matter mortality association is more consistent with the inflammation/ accelerated arteriosclerosis hypothesis. Third, the association between particulate matter and death attributable to dysrhythmias, heart failure, and cardiac arrest supports the altered cardiac autonomic function hypothesis. However, the authors argue that the likelihood of multiple mechanistic pathways with complex interdependencies must be considered when interpreting these results.

As discussed in section 2.2, time-series studies in general analyse the mortality effect of air pollutants in the very short-run, within days of exposure, while cohort studies in general deal with long-term (chronic) effects of air pollution. Zanobetti *et al.* (2003) analysed the effects of PM_{10} on an intermediate time scale, and the potential for short-term mortality displacement. They assessed if deaths associated with particulate air pollution are advanced by a few days or can be advanced for weeks. The authors argued that most studies reporting association between daily deaths and pollution concentrations analysed lags up to two days before, which is a common source of criticism of short-term time-series studies. Some researchers speculate that air pollution kills those who would have died in a few days anyway (harvesting). In fact, some studies analysed this issue using different methodologies, all of them reporting increased, rather than decreased, effects when longer lags were examined (e.g. Schwartz, 2001).

The authors analysed daily counts of "all-cause" mortality, cardiovascular disease mortality and respiratory mortality from 10 cities across Europe and adjacent countries. Mortality data from 1990 to 1997 was divided into age groups: 15-65; 65-74; and older than 75 years. Air pollution data (PM_{10}) were available as daily averages of different monitoring stations in each city. The statistical analyses involved the use of generalised additive regression models (GAM[3]) fitted for each of the ten cities, for respiratory and heart mortality first, then for "all-cause" and stratified respiratory and cardiovascular deaths by age groups. All models controlled for temperature and relative humidity on the same and up to three previous days using non-parametric smooth functions. To remove seasonal and long-term fluctuations, Zanobetti *et al.* (2003) used a smooth function of time. Seasonal patterns are controlled because there are unmeasured predictors of death that have long-term trends over time and vary seasonally, creating a potential for confounding factors. The authors cite diet as an example of such seasonal effect, although they recognise that daily fluctuations in diet are unlikely to be correlated with air pollution. Finally, the dependence of daily deaths on PM_{10} of the present day and up to forty preceding days was examined using an unconstrained distributed lag model and a fourth-degree polynomial distributed lag model.

The harvesting effect would be confirmed if air pollution were negatively associated with deaths several days to weeks afterwards. According to the authors, this association can provide insight if the pollution-related deaths were took forward by a few days or few weeks. An increase of 4.2% in respiratory deaths for a 10-$\mu m/m^3$ increase in PM_{10} concentration was found using the unconstrained distributed lag model, and similar results were found with the polynomial distributed lag models. In contrast, the mean of PM_{10} on the same and previous day was associated with a 0.74% increase in respiratory mortality. The authors found a 1.97% increase in deaths from cardiovascular diseases using the unconstrained distributed lag model and similar results using the polynomial distributed lag models. The study showed that the effect size estimate for airborne particles doubles for cardiovascular deaths when the first forty days after exposure is observed, and increases five times for respiratory deaths. A different pattern of mortality risk over time was found for cardiovascular and respiratory deaths, with the elevation in risk of death after exposure declining more slowly over time for respiratory than cardiovascular deaths. The results suggest that the adverse response to pollution persists for a month or longer after exposure not only for total mortality but also for respiratory and cardiovascular mortality.

Schwartz (2001) developed an analytical framework for examining the harvesting hypothesis, testing if most of the particulate-related events are only being

[3] In this model the mortality outcome is assumed to depend on the sum of non-parametric smooth functions for each variable, allowing the analyst to better model the non-linear dependence of daily deaths on weather and season (Zanobetti *et al.*, 2003).

advanced by a short period of time. It is claimed that if particulate air pollution is only advancing the date of adverse events by few days than it is a less serious public health concern. The proposed approach, which localises the harvesting period in time and examines the association between daily health outcomes and air pollution outside that time scale, was applied to data on respirable particles (PM_{10}) and daily mortality and daily hospital admissions for heart and lung disease in Chicago. An alternative approach to examine harvesting was also proposed, which included analysing separately deaths that occurred inside and outside of hospitals. Schwartz (2001) argued that if the deaths caused by particulate air pollution are primarily in very ill subjects who would die within a few days in any event, those subjects are more likely to die in the hospital than individuals whose condition was not critical and who might have well recovered. Looking at the relative impact of air pollution on deaths by location of death is supposed to be an indirect test of how much of the air pollution-related deaths are only being brought forward by a few days.

Daily death counts were obtained for years 1988 to 1993 for "all-cause" mortality inside and outside hospitals; daily counts of hospital admissions of individuals aged 65 or more for heart disease, pneumonia, and COPD were obtained, along with weather and air pollution data. Long-term trends and seasonal variations were filtered out of the data to avoid confounding by omitted factors, such as smoking habits or respiratory epidemics. These factors may have long-term trends or seasonal patterns that coincide with those of air pollution, but whose short-term fluctuations are unlikely to be correlated with air pollution (Schwartz, 2001). The statistical analysis involved regressing (GAM models using loess smooth functions[4] of the variables) the death counts or hospital admissions on PM_{10} concentrations controlling for time trends, weekday effects, temperature and humidity. The author also used a seasonal and trend decomposition program to decompose the mortality and hospital admission data into different time scales. This method decomposes a single time series into a number of independent time series representing the daily fluctuations that is due to patterns with different time scales. To examine harvesting on different time scales, these seasonally detrended data were smoothed using different windows of 15, 30, 45, and 60 days,

[4] Loess smoothing is a curve-fitting technique, which "estimates a smoothing function by fitting a weighted regression within a moving window, and the weights are close to one in the central third of the window, declining rapidly to zero outside that range, allowing a more flexible control of the variables in a given model" (Sharovsky *et al.*, 2004).

allowing the examination of the association between PM10 and health outcome net of progressively longer displacement of the events.

Schwartz (2001) concluded that the effect-size estimate for deaths outside of the hospital is larger than for deaths inside the hospital, which means that deaths in the hospital, where short-term harvesting is most likely, are less sensitive to air pollution than are deaths outside of the hospital. The result for hospital admissions showed no evidence that most of the effect is short-term harvesting. These results support the finding that when short-term rebound effects are averaged out, the effect size for particulate air pollution increases rather than decreases. Although these results indicate that the deaths and hospital admissions are on average being brought forward by a non-trivial amount of time, they cannot specify what that time is.

Braga *et al.* (2000) investigated the potential confounding effect of respiratory epidemics in the association between air pollution and daily deaths. The authors argued that previous studies that controlled for influenza epidemics using an indicator (dummy) variable for epidemic periods did not provide a systematic analysis to assess whether a control for epidemics changes the air pollution association with mortality in a meaningful way, and did not adequately control for respiratory epidemics. Influenza is not the only pathogen that can produce pneumonia, which suggests that controlling for influenza outbreaks alone may miss some episodes. Braga *et al.* (2000) proposed to model the rise and fall of each respiratory epidemic separately, including those not due to influenza, and check if this changed the associations between air pollution and daily deaths.

Air pollution data were obtained for five U.S. cities with daily PM_{10} monitoring, while "all-cause" mortality data and weather data were provided by official sources. For each city, a generalised additive Poisson regression was fitted, modelling the logarithm of the expected number of daily deaths as equal to the sum of the (loess) smooth functions of the covariates – air pollution, temperature, dew point and barometric pressure on the same day, the previous day's ambient temperature and the day of the week. In order to characterise epidemic periods, the authors used pneumonia hospital admission data for individuals aged 65 or older, including pneumonia caused by pathogens other than influenza and omitting influenza outbreaks that did not produce much life-threatening illness. An epidemic period was defined as the period of 10 days or more of epidemic days, which were defined as those days on which the 3-day moving average of pneumonia hospital admissions was above its 90^{th} percentile.

Braga *et al.* (2000) concluded that, overall, the estimated effect of PM_{10} concentration was reduced by 8% after controlling for respiratory epidemics, the decrease ranging from 3% in Minneapolis to 15% in Seattle. However, the authors argued that these decreases did not modify significantly the association previously observed between air pollution concentration and daily deaths, confirming the strength of the association and supporting causality in this relationship. The study showed that the association between air pollution and the number of daily deaths is robust enough to support controlling for respiratory epidemics, an issue that has been attracting attention among researchers.

Pope *et al.* (2002) assessed the relationship between long-term exposure to fine particulate air pollution and "all-cause", lung cancer and cardiopulmonary mortality, using the same database described before – the American Cancer Society prospective mortality study. The risk factor data for approximately 500,000 adults were linked with air pollution data for several metropolitan areas throughout the United States and combined with socio-economic data, health status, and cause of death data. The authors concluded that long-term exposure to combustion-related fine particulate air pollution is an important environmental risk factor for cardiopulmonary and lung cancer mortality. Each 10-$\mu m/m^3$ elevation in fine particulate air pollution was associated with approximately a 4%, 6%, and 8% increased risk of "all-cause", cardiopulmonary, and lung cancer mortality, respectively.

2.4. Evidence of health impacts of air pollution in Brazil

Epidemiologic studies in Brazil associating air pollution with different health outcomes have been widely developed since the mid nineties, although the literature records that similar studies had been developed since the early seventies (Ribeiro and Cardoso, 2003). Most of the studies were carried out in Sao Paulo since air pollution is more significant in that metropolis than any other city in Brazil. Furthermore, given its geographic characteristics, Sao Paulo is subject to frequent thermal inversions that can lead to a substantial accumulation of atmospheric pollution (Saldiva *et al.*, 1995). Some studies have related air pollution in Sao Paulo to different morbidity outcomes, for example, emergency room visits due to chronic lower respiratory diseases in the elderly (Martins *et al.*, 2002), respiratory symptoms in children aged 11 to 13 years of age (Ribeiro and Cardoso, 2003), ischemic cardiovascular emergency room visits (Lin *et al.*,

2003) and hospital admissions due to respiratory diseases in children (Gouveia and Fletcher, 2000a). Also, Braga *et al.* (1999; 2001) and Lin *et al.* (1999) found a strong association between air pollution and hospital admissions due to respiratory problems for children and adolescents aged 13 years or younger. However, throughout this section attention will be given specifically to the studies relating air pollution in Sao Paulo to mortality effects.

Saldiva *et al.* (1995) analysed the relationship between the daily mortality of elderly people and air pollution in the metropolitan area of Sao Paulo during 1990-1991. Data were obtained with the Municipal Government Obituary – daily records of deaths from natural causes of individuals aged 65 or more that lived within the metropolitan area – and the State Environment Agency – daily measures of relative humidity, daily low temperature, and daily concentrations of sulphur dioxide (measured by coulometry), carbon monoxide (measured by non-dispersive infrared), PM_{10} (measured by beta gauge), ozone (measured by chemiluminescence). The concentrations of the pollutants were estimated as the twenty-four-hour average of available measurements from the ten most centrally located monitoring stations, out of twelve stations distributed in the city of Sao Paulo.

The authors used time series regression models to estimate the association between daily mortality and air pollution, controlling for season (month of year and day of week), weather (e.g. temperature and relative humidity), and other factors. Gaussian regression models were used for the basic analysis, although daily mortality counts are in general modelled with the Poisson distribution[5]. The authors claimed that this procedure was possible given the sufficiently large mean daily mortality observed in Sao Paulo. Models were estimated using lagged moving averages of the air pollution concentrations, and re-estimated observing first-order autocorrelation of the residuals. Measures of individual air pollutants were included in the models altogether and separately. The authors tried various approaches to evaluate the sensitivity of the results to model specification, outliers, or potential confounding of temporal, seasonal, or weather-related factors.

Mortality was associated with suspended particles (PM_{10}), nitrogen oxides, sulphur dioxide, and carbon monoxide. According to the authors, the association with PM_{10} was the most statistically significant, robust and independent of the other

[5] Daily mortality data are in general a count of very rare events, which can be modelled as a Poisson process.

pollutants. An increase in PM_{10} equal to 100 $\mu g/m^3$ was associated with an increase in overall mortality equal to approximately 13%. The authors argued that this association was consistent across different model specifications and estimation techniques (Gaussian and Poisson models). Another conclusion of the study was that the dose-response relationship between mortality and respirable particulate pollution was almost linear, with no evidence of a safe threshold level. Poisson regression techniques showed that the relative risk of mortality for a 100mg/m3 increase in PM_{10} was equal to 1.13 (1.07-1.18 – 95%CI). Saldiva *et al.* (1995) concluded that the close interdependence among the levels of pollutants, mainly PM_{10}, nitrogen oxides and sulphur dioxide, suggests that some caution has to be taken when excluding the participation of any specific pollutants in the process of mortality. Nevertheless, multiple regression models including the mentioned pollutants simultaneously attributed the association with mortality to PM_{10}.

Gouveia and Fletcher (2000b) investigated the association between outdoor air pollution and "all-cause", respiratory and cardiovascular mortality in Sao Paulo, and analysed the role of age and socio-economic status in modifying the association between air pollution and mortality. Daily mortality for age groups was explored during 1991 to 1993, but with an emphasis on children under five years and the elderly. The study was conducted in the city of Sao Paulo instead of the whole metropolitan area surrounding the municipality of Sao Paulo.

According to the authors, data on mortality were provided by the city's mortality information system – PRO-AIM –, which is based on death certificates and assigned by medically qualified personnel to ensure high quality data. Socio-economic data were obtained from the 1991 census. Five socio-economic variables were used to generate a composite index of socio-economic status for each of the 58 administrative districts of Sao Paulo. For each of the socio-economic variables a value was assigned from zero to one in a comparative analysis – from the worst conditions to the best conditions. The composite index was estimated as the mean of these five values for each district. The socio-economic conditions of each subject were characterised based on their district of residence. The local environmental agency – CETESB – provided daily levels of sulphur dioxide measured by colorimetry, PM_{10} measured by a gauge aerosol method, carbon oxide measured by non-dispersive infrared, and ozone and nitrogen dioxide measured by chemoluminescence. For each pollutant, daily levels were calculated by averaging all available data across all monitoring stations in the city of Sao Paulo. The

University of Sao Paulo provided daily data on meteorological variables – temperature, humidity, atmospheric pressure, rainfall, wind speed and direction.

Gouveia and Fletcher (2000b) used Poisson regression models to investigate the association between air pollution and mortality, adjusting for potential confounding factors, initially allowing for longer-term patterns in the data (time trend), then for seasonal and cyclical variations, for short-term systematic (calendar effects) and non-systematic (meteorological) effects. To model the temperature effect, the authors produced correlation functions to characterise at which delay the effect of temperature was greatest on each health outcome. After identifying the best lags, the authors plotted the residuals of the outcomes against the measures of daily temperature at the chosen lags to help determine the shape of the exposure-response relation. Functions with different shapes were tested, including linear, quadratic, two-piece linear, three-piece linear, and non-linear. The effect of each pollutant was investigated on the same day and lagged by one and two days as these were the lags commonly used in similar studies in the literature. Poisson regressions were used to estimate the coefficients of the air pollution variables for different mortality outcomes and age groups. The authors estimated relative risks of death in relation to a change from the 10^{th} to the 90^{th} percentile in levels of each air pollutant.

The authors concluded that "all-cause" "all-age" mortality showed smaller associations with air pollution than mortality for specific causes and age groups. For example, a 3-4% increase in daily deaths of elderly people for all causes and for cardiovascular diseases was associated with an increase in fine particulate matter and sulphur dioxide. For respiratory deaths the increase in mortality was higher – 6% – while cardiovascular deaths were also associated with levels of carbon monoxide, representing a 4% increase in daily deaths. Other conclusions involve associations between air pollutants and mortality in children under 5 years old, which were not statistically significant, and the significant increase in risk of death according to age with effects being more evident in individuals older than 65. Gouveia and Fletcher (2000b) concluded that older age groups seem to be at a higher risk of mortality associated with air pollution in Sao Paulo.

Conceicao *et al.* (2001) evaluated the association between child mortality and air pollution in the city of Sao Paulo from January 1994 to December 1997. Daily records of mortality in children under 5 years of age were obtained from the municipality information programme (PRO-AIM). Pollution data were obtained from the records of eleven monitoring stations of the state agency (CETESB), and weather data (humidity and temperature) were provided by the Institute of Astronomy and Geophysics of the University of Sao Paulo. The authors used generalised additive models in the statistical analysis. According to the authors, such models consider non-parametric smooth functions of the explanatory variables, a Poisson distribution, and a log link. Several models for different sets of explanatory variables were used to evaluate the sensitivity of the pollutant concentration coefficients. The results suggest a significant association between respiratory mortality in children and daily levels of carbon oxide, sulphur dioxide, and PM_{10} in Sao Paulo. The associations with these pollutants were significant even after terms for seasonal variation and weather were included or autocorrelation was considered. This conclusion was coherent with previous child mortality data (Saldiva *et al.*, 1994), and indicates that air pollution in Sao Paulo represents a serious threat to children's health.

Sharovsky *et al.* (2004) analysed the independent effects of environmental variables on daily counts of death from myocardial infarction in Sao Paulo, where 12,007 fatal events were observed from 1996 to 1998. According to the authors, exposure to cold temperatures can increase blood pressure, sympathetic nervous activity, and platelet aggregation in humans, while pollution levels are associated with changes in blood viscosity, heart rate variability, ischemic threshold, and occurrence of life-threatening arrhythmias. All these symptoms are associated with myocardial infarction.

The authors used the Poisson regression in a generalised additive model (GAM) to investigate associations between weather (temperature, humidity, and barometric pressure), air pollution (sulphur dioxide, carbon monoxide, and PM_{10}), and the daily death counts attributed to myocardial infarction. Mortality data were obtained from death certificates provided by the municipal obituary registry and listing myocardial infarction as a primary cause. Daily mean concentration of sulphur dioxide ($\mu g/m^3$), measured by coulometry, carbon oxide (ppm), measured by non-dispersive infrared, and PM_{10} ($\mu g/m^3$), measured with a beta gauge, were provided by CETESB. A loess smooth function was included in the GAM model to control for non-linearity in the dependence of mortality on seasonal trend and temperature. An alternative model was used including ten categories (deciles) for daily temperatures, instead of loess smoothing functions. Similar procedures involved the use of quintiles of relative humidity and sulphur dioxide.

Sharovsky *et al.* (2004) concluded that there is a significant association of daily temperature with deaths due to myocardial infarction, with the lowest mortality being observed at temperatures between 21.6 and 22.6 Celsius. Sulphur dioxide concentrations correlated linearly with myocardial infarction deaths, increasing the number of fatal events by 3.4% for each 10-$\mu g/m^3$ increase. Carbon monoxide and particulate matter did not have significant effects on mortality either individually or when analysed with sulphur dioxide in the final model. The authors argued that their study provides evidence of important associations between daily temperature, air pollution and mortality from myocardial infarction in Sao Paulo, even after a comprehensive control for confounding factors.

Lin *et al.*, (2004) assessed the impact of daily changes in air pollutants (nitrogen dioxide, sulphur dioxide, carbon oxide, ozone, and PM_{10}) on total number of daily neonatal deaths (those that occur between the first and the 28th days of life) in Sao Paulo, from January 1998 to December 2000. The study used pollutant levels obtained at various stations, and the daily averages were considered to be indicative of the pollution level in the whole city. Information on daily minimum temperature and relative humidity was also obtained. Statistical modelling was done using Poisson regression techniques in generalized additive models, using a locally weighted smoothing process to control for time (long-term trend), temperature, humidity, and days of the week. Autoregressive terms were included in the models when the analysis of the autocorrelation plots indicated the necessity of minimising the autocorrelation of the residuals. The effect of air pollutants was estimated using the air pollutant levels on the concurrent day and moving averages from two to seven days in single-pollutant models. Pollutants that presented a positive and statistically significant association with the outcome in single-pollutant models were analysed together – an index of air pollution was created with the pollutants included in the co-pollutant models. The authors concluded that primary pollutants correlated strongly with each other and PM_{10} presented the highest correlations. Ozone presented a negative correlation with carbon monoxide but low and positive correlations with the other primary pollutants. Humidity was correlated inversely with all pollutants, while, as expected, minimum temperature was negatively correlated with primary pollutants but not with ozone. The study reported adverse health effects attributed to the exposure to the air pollutants such as increases in neonatal deaths, which are events correlated with perinatal assistance more than with environmental factors in Brazil. PM_{10} and sulphur dioxide were found to have consistent associations with daily neonatal deaths in a short time lag.

Martins *et al.* (2004) evaluated if the effects of PM_{10} on respiratory mortality of elderly people in Sao Paulo are linked with socio-economic status. The authors undertook a time-series study using data from January 1997 to December 1999. The daily number of elderly respiratory deaths was modelled in generalised linear Poisson regression models controlling for long-term trend, weather, and day of the week, in six different regions of Sao Paulo City. Three socio-economic indicators were used: college education, monthly income, and housing. Martins *et al.* (2004) concluded that for a 10-$\mu g/m^3$ increase in PM_{10}, the percentage increase in respiratory mortality varied from 1.4% to 14.2%. The overall percentage increase in the six regions was 5.4%. The effect of PM_{10} was negatively correlated with both the percentage of people with college education, and with those on a high family income. It was positively associated with the percentage of people living in slums. "These results suggest that socio-economic deprivation represents an effect modifier of the association between air pollution and respiratory deaths" (Martins *et al.*, 2004).

2.5. Conclusions

The adverse health effects of air pollution seem to be widely accepted among researchers nowadays. A number of studies have been developed in the past twenty years suggesting that short-term and long-term exposure to different levels of several air pollutants can be associated with various morbidity effects and mortality. This chapter described the main air pollutants associated with adverse health effects to humans, their characterisations and potential emission sources. In addition, a summary of the different methodologies commonly used in the epidemiologic literature was presented, describing their main features, strength and weaknesses. Finally, a review of the main issues discussed in the international epidemiologic research community was introduced, as well as the recent studies developed in Brazil, especially in Sao Paulo, associating air pollution with mortality trends.

3. Justification of approach and theoretical literature review

This chapter explores the different perspectives to establish appropriate economic values for changes in risks of death. It begins with a description of the approaches that economists use to value changes in risks of human death and, therefore, to estimate the value of a statistical life (VSL). The human capital approach is reviewed in terms of its characteristics and weaknesses. The willingness-to-pay (WTP) approach is then discussed and some of its empirical variations are presented, like the averting behaviour method, the 'compensating-wage' method, the hedonic property value method and the contingent valuation method (CVM or CV). Finally, the adequacy of the willingness-to-pay approach and the contingent valuation method for the purposes of this research are discussed.

In section 3.2 a literature review of economic models is conducted in order to provide the theoretical basis for the willingness-to-pay measures for reduced contemporaneous risks of death, as well as the willingness to pay to reduce future risks. The life-cycle consumption-saving model with uncertain lifetime, the general life-cycle model of consumption, and the Cropper-Sussman model are described and analysed. Finally, some conclusions are presented.

3.1. Different approaches to estimate the value of mortality risk reductions

The purpose of estimating the value of a statistical life is to provide the basis for policy-making involving social decisions. The value of a statistical life is a convenient metric for evaluating policies that reduce risk of death and is represented as the total willingness to pay for the policy that results in one less death in the population. Johansson (1995) defines the value of a statistical life as the aggregate willingness to pay for a measure saving a number of lives divided by the number of lives saved. The appropriate measure of the value of a statistical life from the point of view of government policy is society's willingness to pay for the risk reduction. It is expected that the value of a statistical life may vary with the type of the risk involved in the analysis – if voluntary or involuntary, the initial risk level, the size of the risk change, age and income (e.g. Freeman, 2003 and US EPA, 2000).

Willingness to pay (WTP) in the context of risks to life is defined as "the breakeven payment, per unit reduction in the probability of death, that leaves an individual's overall expected utility unchanged" (Shepard and Zeckhauser, 1982). In a more general context, the willingness to pay for a specific good or service is the sum of the amounts of money individuals spend on the good or service plus the consumer surplus measure associated with the consumption of this good or service. The consumer surplus concept, as introduced by Marshall (1920), is measured as an area to the left of an ordinary or Marshallian demand curve and above the actual price paid by the consumer. The Hicksian or income-compensated consumer surplus is measured as an area to the left of a compensated or Hicksian demand curve, where the individual is held at a certain level of utility through adjustments in his or her income[6].

Researchers have identified two alternative general approaches for valuing the benefits of lifesaving activities, including those associated with environmental programmes: the Human Capital approach and the Willingness-to-Pay approach (Cropper and Freeman, 1991; Shepard and Zeckhauser, 1982; Berger *et al.* 1994; Johansson, 1995). The first approach, based on human capital, estimates the economic productivity of the individual whose life is at risk. It uses an individual's discounted lifetime earnings as its measure of value, assigning valuations in direct proportion to income. The willingness-to-pay approach assumes that the preferences of individuals can be characterised by substitutability between income and safety, that is, individuals make trade-offs between consumption of goods or services and factors that increase the consumer's safety. These trade-offs reveal the values individuals place on their safety or on the reduction on the risks of death.

3.1.1. The human capital approach

The human capital measure is based on the assumption that the value of an individual alive is what this individual produces, and his or her earnings accurately measure that productivity. Alternatively, this approach assumes that the cost to society of a human death is the impact that such death has on national income or output, so that the value of a statistical life is measured in terms of its contribution to national income. This means that the value of preventing someone's death is equal to the gain in the

[6] Freeman (2003), chapter 3, provides a discussion on how the Marshallian consumer surplus compares with the Hicksian welfare measures, such as the compensating variation (CV) – the compensating payment necessary to make the individual indifferent between the original situation and the new price set – and the equivalent variation (EV) – the change in income (given the original prices) that would lead to the same utility change as the change in prices. The CV measure defines the WTP in case of price decrease, and the willingness to accept (WTA) otherwise. Similarly, EV defines a WTA measure for a price decrease and WTP in case of price increase.

present value of his or her future earnings. According to Kuchler and Golan (1999), the use of forgone earnings to measure the value of health and life depends on two assertions; that changes in health status are reflected in earnings and that national income is a reasonable measure of social welfare.

Freeman (2003) formalised the human capital approach and discussed its implementation, although the author clearly stated that this approach is inappropriate for valuing reductions in the risk of death. According to the author, the value of preventing the death of an individual of age (*t*) is the discounted present value of that individual's earnings over his or her remainder expected life:

$$Value = \sum_{i=1}^{T-t} \frac{\pi_{t+i}.E_{t+i}}{(1+r)^i}, \tag{1}$$

where:

π_{t+i} is the probability of the individual surviving from age (*t*) to age (*t*+*i*);

E_{t+i} are the expected earnings at age (*t*+*i*);

r represents the discount rate;

T is the age at retirement from the labour force.

The human capital approach has the appeal of being easy to use, but some ethical issues make it debatable, with several other issues arising when implementing this simple approach to value an individual's risks of death. The most important concerns the choice of a discount rate to calculate the present value of an individual's future earnings. The human capital value of young people would be particularly sensitive to the discount rate utilised. Because of discounting and the time lag before children become productive participants in the labour market, the human capital approach places a much lower value on saving children's lives compared with saving the lives of adults who are in the labour force. Furthermore, all the differences in the labour market structure are reflected in the human capital approach: because of earning differences among individuals of different gender and race, the human capital approach values saving the lives of women and non-whites less than saving the lives of adult white males. Also, this approach assigns no value to retired or totally disabled people's lives.

Cropper and Freeman (1991) provide some criticism of the human capital approach as provider of an approximation for the willingness-to-pay measures for small reductions in risk of death. The first comment concerns the role of non-market production in the measure of productivity, like homemakers and housekeepers. Even when adjustments are made for home production, the method tends to favour males over females, workers over retirees, and higher-paid over lower paid people. The second issue relates to the inclusion (or not) of individuals' own consumption on the measure of his or her productivity. The authors argue that excluding individuals' consumption leaves a measure of the individual's worth, as a producing asset to the rest of society, but this measure is the antithesis of the individualistic premise of conventional welfare economics. Cropper and Freeman (1991) argue that the most important criticism of the human capital approach is the inconsistency with the premises of welfare economics: it is each individual's own preference that counts for establishing the economic values used in cost-benefit analysis.

All the above issues suggest that human capital measures are poor proxies for the willingness-to-pay measure for small changes in the risk of death. It does not reflect the probabilistic nature of death and individuals' different attitudes towards risks.

3.1.2. The willingness-to-pay approach

The willingness-to-pay approach has its basis in the premise that changes in individuals' economic welfare can be valued according to what they are willing (and able) to pay to achieve that change[7]. According to this assumption, individuals treat longevity like a special consumption good and reveal their preferences through the choices that involve changes in the risk of death and the consumption of other economic goods whose values can be measured in monetary terms. That is, in many situations individuals act as if their preference functions include life expectancy or the probability of death as arguments, and make a variety of choices that involve trading off changes in their risk of death for other economic goods. When what is being changed can be measured in monetary terms, the individual willingness to pay is revealed by these choices, which are the basis of the economic value of reductions in the risk of death.

The focus of the willingness-to-pay approach relies on the individualistic dimension of human behaviour, which means that the expressed willingness to pay to reduce the probability of death refers to the individual's own risk. The underlying assumption is that individuals are the best judge of their own welfare and that even in

[7] An alternative value measure based on the assumption of substitutability in preferences is the willingness to accept (WTA), which can be defined as the minimum amount of money the individual would require to voluntarily forgo an improvement that otherwise would be experienced (Freeman, 2003).

matters involving life and death individual preferences must be considered. Thus, the willingness-to-pay measure can be seen to be a reasonable one for use in cost-benefit analysis. However, because the probability of surviving is a normal good, income differences rather than preferences can explain some of the variance in willingness-to-pay estimates.

In health economics literature, some methods for empirical estimation of willingness-to-pay measures have been utilised, each providing a means to derive Hicksian measures for individuals making trade-offs between risks to life and health and other consumption goods and services. These methods are the 'compensating-wage' method, the contingent valuation method, the hedonic price (or hedonic property value), and the averting behaviour method.

- **'Compensating-wage' method**

According to Kuchler and Golan (1999), the 'compensating-wage' method was the predominant empirical approach to assess willingness to pay for risk reductions until the late nineties. It uses the labour market data on wage differentials for jobs with different levels of health risks, assuming that workers understand the workplace risk involved, and that the additional wage that workers receive when they undertake risky positions reflects risk choice. In other words, the 'compensating-wage' approach relies on the assumption that workers will accept exposure to some level of risk in return for some compensation. In general, a hedonic-wage function is estimated where wages are specified as a function of personal characteristics of the worker – income, age, sex, education, and health status - and the characteristics of the job. Among the latter, the fatality risk level of the job, benefits paid in case of injury on the job and benefits in the event of a fatal accident can be cited as examples.

Formally, Freeman (2003) supposes that each individual chooses a job so as to maximise the expected utility from consumption of the numeraire, (X), and from the vector of job characteristics (J). Additionally, each job is characterised by its risk of accidental death, (δ_i), where (i) indices jobs. Individuals face a hedonic wage function that is the locus of points at which firms' marginal wage equals workers' marginal acceptance:

$$p_w = p_w(\delta, J)\,, \tag{2}$$

where (p_w) is the weekly or monthly wage. The individual chooses job (i) to maximise expected utility subject to the wage constraint:

$$\text{Max } E(u) = \pi.u(X,J) + \lambda.(p_w(\delta,J) - X)\,, \qquad (3)$$

where (λ) is the marginal (expected) utility of income and (π) is the probability of surviving the period and being able to consume (X). In wage-risk studies it is risk of death, (δ), rather than survival probability, (π) that is observed. The relationship between them is given by ($\pi = [1\text{-}\delta].[1\text{-}\phi]$), where ($\phi$) is the probability of dying from a non-work related cause. Since (ϕ) is usually small, (π) is approximately equal to ($1\text{-}\delta$). The first order conditions governing the choices of (X) and job risk are:

$$\pi_i.\frac{\partial u}{\partial X} = \lambda \qquad (4)$$

$$\frac{u(X,J)}{\lambda} = \frac{\partial p_w}{\partial \delta_i} \qquad (5)$$

$$\frac{\pi_i.\partial u/\partial J_j}{\lambda} = -\frac{\partial p_w}{\partial J_j}\,, \qquad (6)$$

for all job (i) characteristics (J_j).

From equation (4), (λ) is the expected marginal utility of consumption, which is by assumption positive. According to equation (5), the marginal willingness to pay for an increase in the probability of surviving the job risk must equal its marginal implicit price. Equation (5) also implies that wages must be lower for jobs that are safer, that is, the marginal implicit price of an increase in (π_i) is a decrease in the wage rate. Equation (6) requires that the marginal willingness to pay for each job characteristic equal its marginal implicit price. In summary, the risk premium associated with a higher risk job must be equal to the individual's marginal willingness to accept compensation for risk.

According to Viscusi (1993), the main empirical approach to assess risk trade-offs in the labour market has utilised hedonic-wage equations. Controlling for other aspects of the job, it estimates the wage premium workers receive for risk, which is the interaction of labour demand by firms and labour supply decisions by workers. Assuming that a greater workplace safety would increase firm's costs, to maintain the same level of profits along some isoprofit curve the firm would pay lower wage rates to compensate for the cost of providing a safer work environment. As a consequence, the firm's wages offer curve would be an increasing function of risk.

The supply side of the labour market is characterised by several restrictions on worker's preferences. Viscusi (1993) considered an expected utility model with state-dependent utilities, where *U(w)* denoted the utility of being healthy and *V(w)* denoted the utility of being injured. The only critical assumptions required for workers to demand compensating differentials for risk are that the worker would rather be healthy than injured (*U(w)>V(w)*), and the marginal utility of income is positive (*U'(w) >0, V'(w)>0*). It is not necessary to assume that individuals are risk averse in their attitude toward financial gambles (*U"<0, V"<0*), workers would select the available wage-risk combination that maximises their expected utility. Wage-risk combinations that maintain an expected utility level *(Z)* constant are given by:

$$Z = (1-p).U(w) + p.V(w), \qquad (7)$$

where, (*w*) is the wage and (*p*) represents the risk involved. The wage-risk tradeoff along this curve is given by:

$$\frac{dw}{dp} = -\frac{Z_p}{Z_w} = \frac{U(w)-V(w)}{(1-p).U'(w)+p.V'(w)} > 0, \qquad (8)$$

which means that the required wage rate increases with the risk level.

The observable points in the labour market are, in fact, particular wage-risk choices of different workers at points of tangency with the market opportunity curve. The econometric task of the hedonic wage methodology is estimating the locus of these wage-risk trade-offs for the entire market. The estimated rate of trade-off (*dw/dp*) provides a local measure of the wage-risk trade-off for marginal changes in risk. For any given worker located along the hedonic wage curve, "the estimated slope simultaneously reflects the marginal willingness to accept risk and the marginal willingness to pay for greater safety. The points on this curve also represent the points of tangency of firms' offer curves with workers' constant expected utility loci. The slope for the firm reflects both the marginal cost of greater safety and the marginal cost reductions from an incremental increase in risk. The slope at any point (dw_i/dp_i) consequently represents the marginal supply price as well as the marginal demand price of risk for both the worker and firm located at that point" (Viscusi, 1993).

'Compensating-wage' models are consistent with the willingness-to-pay approach in the sense that they recognise that individuals have unique preferences over risky alternatives and that they have opportunities to reduce risks, depending on their labour skills. These models postulate that part of the differences in risk preferences is systematic and depends on objective and measurable individual characteristics.

- **Contingent valuation method (CVM)**

Contingent valuation is a survey method in which respondents are asked to state their preferences in hypothetical or contingent markets, allowing analysts to estimate demands for goods or services that are not traded in markets. In general, the survey draws on a sample of individuals who are asked to imagine that there is a market where they can buy the goods or service evaluated. Individuals state their maximum willingness to pay for a change in the provision of the goods or service, or their minimum compensation (willingness to accept) if the change is not carried out. Socio-economic characteristics of the respondents such as gender, age, income, education, and demographic information are also obtained. If it can be shown that individuals' preferences are not random, but that instead they vary systematically and are conditioned to some observable demographic characteristics, then population information can be used to forecast the aggregate willingness to pay for the goods or service evaluated. The contingent valuation method has been widely used for estimating environmental benefits in particular.

There is a large body of literature on the advantages and disadvantages of the contingent valuation method (Mitchell and Carson, 1989; Bateman *et al.*, 2002). The central problem in a contingent valuation study is to make the scenario sufficiently understandable, clear and meaningful to respondents, who must understand clearly the changes in characteristics of the goods or service he or she is being asked to value. The mechanism for providing the goods or service must also seem plausible in order to avoid scepticism that the goods or service will be provided, or the changes in characteristics will occur. Table 1 provides a summary of the main biases that, according to Mitchell and Carson (1989), can be generated in a contingent valuation study.

The most serious problem related to contingent valuation studies may be the fact that the method provides hypothetical answers to hypothetical questions, which means no real payment is undertaken. This fact may induce the respondent to overlook his or her budget constraint, consequently overestimating his or her stated willingness to pay. Another criticism refers to the fact that researchers cannot know for sure that individuals would behave in the same way in a real situation as they do in a hypothetical exercise.

Table 1: Typology of potential response effect biases in contingent valuation

1) *Incentives to misrepresent responses*

Biases in this class occur when a respondent misrepresents his or her true willingness to pay (WTP)

A *Strategic bias*: where a respondent gives a WTP amount that differs from his or her true WTP amount (conditional on the perceived information) in an attempt to influence the provision of the good and/or the respondent's level of payment for the good.

B *Compliance bias*

i *Sponsor bias*: where a respondent gives a WTP amount that differs from his or her true WTP amount in an attempt to comply with the presumed expectations of the (assumed) sponsor.

ii *Interviewer bias*: where a respondent gives a WTP amount that differs from his or her true WTP amount in an attempt to either please or gain status in the eyes of a particular interviewer.

2) *Implied value cues*

These biases occur when respondents treat elements of the contingent market as providing Information about the 'correct' value for the good.

A *Starting point bias*: where the elicitation method or payment vehicle directly or indirectly introduces a potential WTP amount that influences the WTP amount given by a respondent

B *Range bias*: where the elicitation method presents a range of potential WTP amounts that influences a respondent's WTP amount.

C *Relational bias*: where the description of the good presents information about its relationship to other public or private commodities that influences a respondent's WTP amount.

D *Importance bias*: where the act of being interviewed or some feature of the instrument suggests to the respondent that one or more levels of the amenity has value.

3) *Scenario misspecification*

Biases in this category occur when a respondent does not respond to the correct contingent scenario. Except in A, in the outline that follows it is presumed that the intended scenario is correct and that the errors occur because the respondent does not understand the scenario as the researcher intends to be understood.

A *Theoretical misspecification bias*: where the scenario specified by the researcher is incorrect in terms of economic theory or the major policy elements.

B *Amenity misspecification bias*: where the perceived good being valued differs from the intended one.

i *Symbolic*: where a respondent values a symbolic entity instead of the researcher's intended good.

ii *Part-whole*: where a respondent values a larger or a smaller entity than the researcher's intended good.

a *Geographical part-whole*: where a respondent values a good whose spatial attributes are larger or smaller than the spatial attributes of the researcher's intended good.

b *Benefit part-whole*: where respondent includes a broader or a narrower range of benefits in valuing a good than intended by the researcher.

c *Policy package part-whole*: where a respondent values a broader or narrower policy package than the one intended by the researcher.

iii *Metric:* where a respondent values the amenity on a different (and usually less precise) metric scale than the one intended by the researcher.

iv *Probability of provision*: where a respondent values a good whose probability of provision differs from that intended by the researcher.

C *Context misspecification*: where the perceived context of the market differs from the intended context.

i *Payment vehicle*: where the payment vehicle is either misperceived or is itself valued in a way not intended by the researcher.

ii *Property right*: where the property right perceived for the good differs from that intended by the researcher.

iii *Method of provision*: where the intended method of provision is either misperceived or is itself valued in a way not intended by the researcher.

iv *Budget constraint*: where the perceived budget constraint differs from the budget constraint the researcher intended to invoke.

v *Elicitation question*: where the perceived elicitation question fails to convey a request for a firm commitment to pay the highest amount the respondent will realistically pay before preferring to do without the amenity.

vi *Instrument context*: where the intended context or reference frame conveyed by the preliminary non-scenario material differs from that perceived by the respondent.

vii *Question order*: where a sequence of questions, which should not have an effect, does have an effect on a respondent's WTP amount.

Source: Mitchell and Carson (1989) and Johansson (1995).

In the context of risk and safety, the contingent valuation method involves asking members of a representative sample of the population-at-risk about their willingness to pay for a small hypothetical improvement in their safety. According to Beattie *et al.* (1998), people's *ex-ante* willingness to pay to reduce risk will tend to vary with their perceptions of the attitudes towards the characteristics of different hazards. For example, the extent to which the hazard analysed is seen to be voluntarily assumed, under the potential victims' own control. The authors argue that there is evidence of apparent anomalies and inconsistencies in responses to willingness-to-pay questions in the safety and environmental fields. The most common inconsistencies involve embedding (Table 1, item 3-B-ii), scope (Table 1, item 3-B-iii) and sequencing effects (Table 1, item 3-C-vii). The first two effects refer to the tendency of many contingent valuation respondents to report the same willingness to pay for a comprehensive bundle of safety or environmental good as for a proper subset of the bundle[8]. Sequencing effects reflect a tendency for the order in which a sequence of contingent valuation questions is presented to respondents to have a significant impact on the willingness-to-pay responses.

[8] Kahneman and Knetch (1992) questioned the validity of the contingent valuation method for evaluating public goods based on an experimental investigation: "...the assessed value of a public good is demonstrably arbitrary, because willingness to pay for the same good can vary over a wide range depending on whether the good is assessed on its own or embedded as part of a more inclusive package...contingent valuation responses reflect the willingness to pay for the moral satisfaction of contributing to public goods, not the economic value of these goods" (Kahneman and Knetch, 1992). However, Smith (1992) argued that Kahneman and Knetch (1992) failed to specify correctly the nature of the issues involved in their experiment, and demonstrated that the 'regular' type of embedding – the type characterised by the embedding of substitute goods under an umbrella good (Bennet *et al.*, 1998) – in fact is to be expected under conventional (neo-classical) economic assumptions. A second type of embedding, referred to as 'perfect' embedding or 'part-whole' problem, can be explained by factors that include lack of familiarity regarding the good being valued or the inability of respondents in distinguishing between small changes in the good (Bennet *et al.*, 1998). I return to this discussion in the next section.

- **The hedonic price or property value method**

The hedonic price model provides the basis for deriving welfare measures from observed differences in properties' prices. The method is based on the assumption that house characteristics yielding differences in health risks across houses are reflected in property value differentials. Just as wages are higher in risky occupations to compensate workers for their increased risks to life, property values may be lower in areas where lives are at risk, to compensate residents for those increased risks. The property market is then used to infer the willingness to pay to reduce risk of death, through a hedonic price function.

Freeman (2003) provided a basic model for the hedonic property value method used to value environmental amenities. The author assumed that each individual's utility is a function of: the individual's consumption of a composite commodity (*X*); a vector of location-specific environmental amenities (*Q*); a vector of the structural characteristics of the house the individual occupies[9], (*S*); and a vector of the characteristics of the neighbourhood in which the house is located[10] (*N*). An important assumption of the hedonic technique is that the urban area as a whole can be treated as a single market for housing services, and individuals should have information on all alternatives and must be free to choose a house anywhere else in the urban market.

Once the interest was in the values of characteristics to buyers of houses, Freeman (2003) argued that there was no need to model formally the supply side of the property market. The author simply assumed that the housing market was in equilibrium, that is, that all individuals have made their utility-maximising residential choices given the prices of alternative housing locations, and that these prices just cleared the market given the existing stock of houses and its characteristics. Given these assumptions, the price of the (*i*th) residential location can be taken to be a function of the structural, neighbourhood, and environmental characteristics of the location:

$$P_{hi} = P_h(S_i, N_i, Q_i) \qquad (9)$$

Equation (9), when considering the individuals and their choices observed in the housing market, is called the hedonic price function of properties and can be econometrically estimated. The coefficient relative to the environmental amenity gives the marginal change in house prices given a marginal change in the environmental

[9] Characteristics like size, number of rooms, age, and type of construction.
[10] For example, quality of local schools, accessibility to parks, stores, and work place, and crime rates.

amenity. This coefficient reflects how individuals value changes in environmental amenities in the housing market. The same approach can be used to estimate how individuals value changes in their risk of death in the housing market.

Freeman (2003) concluded that the major limitation of the hedonic price model is the assumption that consumers are able to select their most preferred bundle of house characteristics from a complete range of levels of all characteristics. Also, the derivation of welfare measures for changes in the levels of environmental amenities is especially difficult for non-marginal amenity changes. Values for marginal changes in amenity levels can be estimated by adding up the observed marginal willingness to pay for all affected individuals. However, for non-marginal changes, welfare measurement requires knowledge of the inverse demand function or the income-compensated bid function for the amenity.

- **The averting behaviour method**

This method assumes that individuals spend some of their money on activities that reduce their risk of death, such as buying smoke detectors, and that these activities are pursued to the point where their marginal cost equals their marginal value of reduced risk of death. The marginal costs incurred by individuals to reduce their probability of death are used to evaluate individuals' willingness to pay to reduce their risk of death. Given individual data on the marginal costs of an averting good, which is likely to vary among individuals, and data on the effect of the averting good on the probability of death, the individual's willingness to pay can be estimated. The most relevant measure of the effect of the averting behaviour on risk of death is, according to Cropper and Freeman (1991), the individual's perception of this risk reduction. Although relevant, these perceptions are difficult to be observed and in general no data are available.

The key criticism of the averting behaviour method is that the actual activities used in most studies, such as wearing seatbelts or purchasing smoke detectors, are yes/no decisions. This means that the consumer decides or not to buy the averting good provided his or her marginal benefit is not less than the marginal cost of purchasing the good. The marginal cost equals the marginal benefit only for the last person to purchase the averting good, for all other consumers, the willingness to pay exceeds the marginal cost of a reduction in the conditional probability of death. To overcome this problem, the general procedure for estimating the willingness to pay to reduce risk of death requires data on the cost of the averting activity and data on its effects on reducing the risk of death for a cross-section of individuals. If both the marginal costs and the probabilities of death vary among individuals then it is possible to estimate the average willingness to pay using a probit or logit model of averting behaviour.

Another problem with the averting behaviour method arises when the averting activity produces joint benefits, such as when it reduces the risk of injury or property damage as well as the risk of death. In practice, researchers deal with this problem either by treating the value of joint products as zero, and then obtaining an upper bound to willingness to pay, or by assuming that the value of injury is some fraction of the value of a statistical life. Cropper and Freeman (1991) conclude that because of the problems cited above, especially the discreteness of the averting activity, the estimates of the value of a statistical life obtained from the averting behaviour method are lower than estimates obtained from other valuation methods.

3.1.3. The adequacy of the willingness-to-pay approach and the contingent valuation method for this study

The different approaches discussed in the previous sections are all associated with important advantages and disadvantages. The human capital approach fails to be consistent with the premises of welfare economics, where the individual's own preferences are what count for establishing the economic values used in cost-benefit analysis. This feature of the human capital approach indicates that the willingness-to-pay approach might be the best alternative to estimate the benefits of life saving programmes, the objective of which include reducing the probabilities of death.

Given that the willingness-to-pay approach seems to be the appropriate approach for the purposes of this research, the next step involves the choice of an adequate valuation method. As argued by Viscusi (1992): "adopting the willingness-to-pay approach and establishing empirical estimates considerably simplify the task of addressing value-of-life issues in policy contexts. For private decisions the dominant concern will be the private willingness-to-pay amount. For public choices it will be society's overall willingness to pay for the risk reduction. One would expect that the greatest benefit from a life-extension policy would be that received by the individual whose life is directly affected, so private valuations provide a good starting point for assessing the value of life" (Viscusi, 1992).

The major problem of the indirect methods, those where individuals reveal their preferences through market decisions, is to isolate the risk-income trade-off from other factors and to take into account the institutional restrictions of the observed markets (labour and property markets, for instance). Also, the application of these methods is limited to those risks that are traded in markets, when the need of information about the value of changes in probabilities of death is greater in areas where no market exists, like health and environmental areas.

In particular, the 'compensating-wage' method estimates the value of a statistical life based on information of the labour market, where older people are generally absent. Since older people have fewer life-years remaining than young people the compensation received in labour market studies may overstate the value of risk reductions to old people. In addition, "much of the criticism of the 'compensating-wage' approach centres on its assumptions concerning the labour market. Many critics argue that the actual labour market bears little resemblance to the labour market described in 'compensating-wage' models. The 'compensating-wage' approach assumes that workers are fully cognisant of the extent and consequences of the on-the-job risks they face, that labour market is strictly competitive, and that insurance markets are actuarially correct, with premiums and payouts matched to accurately assessed risks" (Kuchler and Golan, 1999).

While the contingent valuation method overcomes the problems of the 'compensating-wage' method, its disadvantage is the fact that little is known about the extent to which answers to hypothetical questions actually represent the respondent's behaviour or preferences. It has become an important tool for evaluating changes in probabilities of death caused by public policies focused on safety, health or environmental expenditures. It is particularly attractive in situations where changes in death risks are not readily estimated using revealed preference techniques. In the particular context of this research, the contingent valuation method seems to be adequate for the purposes of the study. First, because the objective of the study is to estimate the main benefit of air pollution reduction programmes, the reduction in probabilities of death of the population, and second, the limitations of other methods based on the willingness-to-pay approach seem to confirm that the contingent valuation method is appropriate.

As noted in Section 3.1.2, a point to be observed when using the contingent valuation method for eliciting the willingness to pay for a reduction in probabilities of death is how sensitive the estimates are to changes in risk. Economic theory suggests that willingness to pay to reduce small probabilities of death should increase with the magnitude of risk reduction, and approximately proportional to this magnitude, assuming that risk reduction is a desired good. For example, if a reduction in annual mortality risk is valued at a certain amount of money, then a larger reduction in risk should be valued at a larger amount of money. In addition, the difference between the values should be proportional to the difference in risks, ignoring the income effect.

Hammitt and Graham (1999) discuss some reasons why stated willingness to pay is frequently not sensitive to variation in risk magnitude. One possible reason, they argue based on the review of several studies, is that respondents might not understand probabilities, or lack intuition for the changes in small probabilities of death risk. Another possibility involves the fact that respondents might not treat the given probabilities as applying to them. In that case, willingness to pay would not be proportionate to the amount of risk reduction given to respondents, but proportionate to changes in perceived risk. Finally, it is possible that respondents might not value changes in risk levels in a manner that is consistent with expected utility theory (section 3.2).

In summary, in a reliable contingent valuation study involving small changes in probabilities of death, tests should be performed to evaluate how sensitive willingness-to-pay estimates are to changes in risks. An 'internal' test of sensitivity to magnitude, the one performed within one sample, occurs when the respondent informs different willingness to pay for different changes in risk in the same questionnaire. An 'external' test of sensitivity to magnitude occurs when different samples are used to compare the willingness-to-pay estimates, meaning that different respondents are asked about their willingness to pay for different risk reductions and there is no possibility of co-ordinating their responses. Internal tests are more likely to be successful because respondents in general base their responses to willingness-to-pay questions about one risk reduction on their answers to previous questions about a different risk change, anchoring their answers on their previous responses, which enforces some degree of consistency.

3.2. Theoretical literature review

The theoretical framework that has been used to develop the economic models that define willingness to pay for a change in health risks is based on economic models of individual choice that focus on the conditional probability of death under an uncertain lifetime. Such models are based on the interplay between the 'impatience' to consume and the productivity of resources. The models offer insight into consumption, saving, investment, portfolio selection and purchase of life insurance and annuities (Shepard and Zeckhauser, 1982). They are based on the assumption that individuals maximise their expected utility by choosing among alternatives, some of which change their risk of dying[11] (as in the discussion on the compensating-wage method, section 3.1.2, equation (3)). Thus, the willingness to pay for a reduction in the risk of death is the maximum amount that can be taken from the individual without reducing his or her expected utility. They also generate predictions about how willingness to pay varies with age and lifetime earnings, providing the theoretical basis for many empirical studies of willingness to pay for reduction in health risks.

The main models that provide the theoretical foundation for studies of willingness to pay for health risk reduction are presented below.

3.2.1. The life-cycle consumption-saving model with uncertain lifetime: the Fisher-Yaari framework

In the 1930s, Fisher (1930) developed a general framework to analyse the allocation of consumption over an individual's lifetime. He was aware of the uncertainty of an individual's survival, but did not explore how the consumer might be expected to behave rationally under this uncertainty.

Yaari (1965) concentrated his discussion entirely on the uncertainty of lifetime and ignored the other uncertainties that a consumer generally faces. He started the

[11] Kahneman and Tversky (1979) presented a critique of expected utility theory as a descriptive model of decision-making under risk, and developed an alternative model named *Prospect Theory.* The authors, both psychologists, described several classes of choice problems in which individuals' preferences seem to violate the axioms of expected utility theory, and concluded that individuals are highly sensitive to how choices are presented to them (framing of the alternatives involving risk). For example, individuals are risk-averse when offered a choice formulated in one way, but are risk-taker when offered the same choice formulated or framed in a different way. Another important conclusion of Kahneman and Tversky (1979) refers to the subjective assessments of probabilities that individuals seem to assume when deciding between choices under risk, which may differ from the actual probabilities involved. One possible implication of these results for the validity of contingent valuation results has already been discussed in footnote 8.

discussion with the "Fisher-type" analysis of allocation over time, supposing that the consumer's preferences are represented by a utility function (*V*), the Fisher utility function:

$$V(c) = \int_0^T \alpha(t).g[c(t)]dt \qquad (10)$$

V(c) is the utility of the consumption plan (*c*);

T corresponds to years that a consumer expects to live;

c is an arbitrary consumption plan. A real valued function defined on the interval [0,*T*];

c(t) is the rate of expenditure on consumption that takes place at time (*t*) if the plan (*c*) is adopted;

α is a subjective discount function; a non-negative real valued function defined on the interval [0,*T*];

g is the utility associated with the rate of consumption at every moment of time. A concave real valued function defined on the interval [0,∞);

Equation (10) has an implicit assumption that the consumer's preferences are independent over time, which is a strong but necessary assumption to make the problem manageable. The objective is to maximise (*V(c)*) subject to a wealth constraint, for which the author assumes the possibility of unrestricted borrowing, the existence of a single interest bearing asset and the re-contracting of all outstanding loans at every moment of time. It is also assumed that the consumer's initial asset is zero. Thus, the consumer's net assets at time (*t*) are:

$$S(t) = \int_0^t \{\exp \int_\tau^t j(x)dx\}.\{m(\tau) - c(\tau)\}d\tau \qquad (11)$$

S(t) is the consumer's net asset at time (*t*);

$j(\tau)$ is the rate of interest which is expected to prevail at time (τ);

$m(\tau)$ is the rate of earnings (other than interest) at time (τ);

The wealth constraint is given by the inequality:

$$S(T) \geq 0 \qquad (12)$$

A consumption plan would be admissible if the following three conditions hold:

(*c*) is bounded and measurable;

($c(t) \geq 0$) for all t in [0, T];

$$\int_0^T \{\exp \int_t^T j(x)dx\}.\{m(t) - c(t)\}dt = 0$$

The Fisher problem, that is, to find an admissible plan of consumption (c^*) such that [$V(c^*) \geq V(c)$] for all admissible plans (c), does not always have a solution. But if it does have a solution, then the following statements are true: the optimal plan (c^*) is continuous on the interval [0, T], it is differentiable wherever it is positive, and wherever (c^*) is positive it satisfies the following fundamental differential equation:

$$\dot{c}(t) = -\left\{ j(t) + \frac{\dot{\alpha}(t)}{\alpha(t)} \right\} . \frac{g'[c^*(t)]}{g''[c^*(t)]} \qquad (13)$$

The quantity $-\frac{\dot{\alpha}(t)}{\alpha(t)}$ can be regarded as the consumer's subjective rate of discount[12]. Thus, equation (13) says that the optimal consumption plan increases wherever the rate of interest is greater than the rate of subjective discount, and it is decreasing wherever the rate of subjective discount is greater than the rate of interest.

Now Yaari (1965) leaves the Fisher problem under complete certainty related to (T) and supposes that (T) is now a random variable with a known probability distribution, and so is the Fisher utility function (V). One problem arises because it is meaningless to speak about maximisation of a random variable (V), since its value is likely to be different for each value of the random variable (T). To overcome this problem the author utilises the expected utility hypothesis, in which the consumer will select a consumption plan that maximises the expected value of (V).

The same difficulty happens with the wealth constraint, that also depends on (T), so that a given consumption plan may be admissible for one value of (T) but inadmissible for other values (feasibility problem). To overcome the feasibility problem, Yaari considers two procedures suitable to the context of the study: the chance-constrained programming procedure and the penalty function procedure (or loss-function procedure). The first approach requires that the wealth constraint be met with probability (λ) or more, where (λ) is a number fixed in advance. Thus, what the chance-constrained programming procedure does is replace the deterministic constraint (12) by the probabilistic constraint:

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[12] For example, if $\alpha(t) = e^{-kt} \Rightarrow \dot{\alpha}(t) = \frac{\partial \alpha(t)}{\partial (t)} = -k.e^{-kt} \Rightarrow -\frac{\dot{\alpha}(t)}{\alpha(t)} = k.\frac{e^{-kt}}{e^{-kt}} = k$, where $\dot{\alpha}(t)$ is the differentiation with respect to *(t)* of the discount function, $\alpha(t)$.

$$prob\{S(T) \geq 0\} \geq \lambda . \tag{14}$$

It is of interest to examine what the consumer's optimal plan looks like given that the wealth constraint (12) must hold with probability equal to one. This is due to the idea that the institutional framework of modern society makes it virtually impossible for an individual to die with a negative net worth.

The other approach to cope with the feasibility problem, penalty function or loss-function procedure, charges the consumers themselves with protecting the wealth constraint by assuming that a violation of the constraint implies a loss of utility. Thus, the total utility of a consumption plan (c) for a lifetime of length (T) is given by ($V(c)+\varphi[S(T)]$), where (φ) is a non-decreasing concave real function defined on ($-\infty,\infty$) that describes a penalty for violation of the wealth constraint. Since (φ) is non-decreasing, a positive ($S(T)$) increases utility and a negative one decreases utility, but only the latter possibility represents a loss of utility. Then, one further condition must be imposed:

$$\varphi(x) = 0 \text{ for } x \geq 0 \quad \text{and}$$
$$\varphi(x) < 0 \text{ for } x < 0 \tag{15}$$

The new utility function (U) is defined in (16) and it is assumed that the consumer attempts to find the consumption plan, which maximises the expected utility without any constraints.

$$U(c) = \int_0^T \alpha(t).g[c(t)]dt + \varphi[S(T)] \tag{16}$$

Yaari (1965) still considers the bequest size and time problems, which are the importance the consumer gives to the size of his or her wealth at the moment of his or her death and to the time at which it is made. To accommodate this possibility, the author introduces a subjective weighting function for bequests (β) into the Marshallian[13] utility function (U):

$$U(c) = \int_0^T \alpha(t).g[c(t)]dt + \beta(T).\varphi[S(T)] \tag{17}$$

In summary, two alternatives were formulated by Yaari (1965) to describe the consumer's behaviour when faced with the uncertainty of lifetime. The first, (Case A), sees the consumer as attempting to maximise the expected value of a Fisher utility

[13] Reference to Alfred Marshall who "gave particular emphasis to family affections as a motive for saving." (Yaari, 1965)

function, subject to a non-negative net asset at the moment of his or her death with probability equal to one. The second, (Case B), considers the consumer maximising a Marshallian utility function, subject to no constraints, since the loss for negative bequests is incorporated in the utility function. The solutions to both cases are then described and analysed, starting with Case A.

Equation (10) gives the Fisher utility function for a fixed lifetime (T), which is assumed to be a random variable in the interval $[0, \bar{T}]$ with probability density function (π):

$$\pi(t) \geq 0 \text{ for all t} \qquad \text{and}$$

$$\int_0^{\bar{T}} \pi(t)dt = 1 \qquad (18)$$

The probability that the consumer will be alive at time (t), ($\Omega(t)$), and the value of the conditional density of (T), at moment (τ), ($\pi_t(\tau)$), are given by:

$$\Omega(t) = \int_t^{\bar{T}} \pi(\tau)d\tau, \qquad 0 \leq t \leq \bar{T} \qquad (19)$$

and

$$\pi_t(\tau) = \frac{\pi(\tau)}{\Omega(t)}, \qquad 0 \leq t \leq \tau \leq \bar{T}, t \neq \bar{T} \qquad (20)$$

Then, the expected utility ($\bar{V}(c)$) of the plan (c) is given by:

$$\bar{V}(c) = EV(c) = \int_0^{\bar{T}} \pi(t).\int_0^t \alpha(\tau).g[c(\tau)]d\tau.dt \qquad (21)$$

By a change in the order of integration in (21)[14] and using (19):

$$\bar{V}(c) = \int_0^{\bar{T}} \Omega(t).\alpha(t).g[c(t)]dt \qquad (22)$$

The problem in Case A is to find an admissible consumption plan (c^*) such that ($\bar{V}(c^*) \geq \bar{V}(c)$), for all admissible plans (c). A plan is considered to be admissible if it is bounded, measurable, non-negative and satisfies the wealth constraint (12) with probability one. If such a plan does exist then its properties can be obtained by using standard calculus of variation technique.

Under the assumption that ($\pi(t) > 0$) for $0 < t < \bar{T}$, the constraint:

$$prob\{S(T) \geq 0\} = 1 \qquad (23)$$

Is equivalent to

$$S(T) \geq 0 \text{ for all t} \tag{24}$$

Now for ($t = \overline{T}$), (24) will hold with equality for sure, but for other values of (t) it is convenient to convert the constraint (24) to:

$$\dot{S}(t) \geq 0 \text{ whenever } S(t) = 0 \tag{25}$$

From the definition of (S) (equation (11)):

$$\dot{S}(t) = m(t) - c(t) + j(t).S(t) \tag{26}$$

Thus, what the requirement (25) says is that ($c(t) \leq m(t)$) whenever ($S(t)=0$). The problem becomes:

Maximise

$$\int_0^{\overline{T}} \Omega(t).\alpha(t).g[c(t)]dt = \int_0^{\overline{T}} \Omega(t).\alpha(t).g[m(t) - \dot{S}(t) + j(t).S(t)]dt \tag{27}$$

subject to: (i) $c(t) \geq 0$ for all t;

(ii) $c(t) \leq m(t)$ whenever $S(t)=0$;

(iii) $S(\overline{T}) = 0$.

In general, the solution (c^*) will be composed of three segments: the first one, in which ($c^*(t)=0$), constraint (i) being effective (bounded solution); the second, when constraint (ii) is effective, ($c^*(t) = m(t)$); and finally, the interior solution in which neither constraint is effective. Whenever (c^*) is interior, it must satisfy the differential equation:

$$\dot{c}(t) = -\left\{ j(t) + \frac{\dot{\alpha}(t)}{\alpha(t)} - \pi(t) \right\}.\frac{g'[c^*(t)]}{g''[c^*(t)]}, \tag{28}$$

where $\pi(t) = {\dot{\Omega}(t)}/{\Omega(t)}$.

The interesting result that emerge when equation (28) is compared to equation (13), the analogous result in the absence of uncertainty related to the time of death, is that they are coincident except that the subjective rate of discount is now given, for time (t), by

$$\pi(t) - \frac{\dot{\alpha}(t)}{\alpha(t)}, \tag{29}$$

that is always greater than the consumer's subjective rate of discount with certainty

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[14] This is possible because c is assumed to be bounded and measurable.

$\left(-\frac{\dot{\alpha}(t)}{\alpha(t)}\right)$. In summary, the future is discounted heavily because of the uncertainty of survival.

Analysing Case B, where the consumer is concerned with his or her bequest at time of death, the problem becomes one of maximising the expected value of (17), subject to no wealth constraints, since the loss for negative bequests is incorporated in the utility function[15]. Writing the expected value of the Marshallian utility function and changing the order of integration:

$$\overline{U}(c) = EU(c) = \int_0^{\overline{T}} \{\Omega(t).\alpha(t).g[c(t)] + \pi(t).\beta(t).\varphi[S(t)]\}dt \qquad (30)$$

The result of the maximisation problem above produces the optimal consumption plan (c^*) and the corresponding asset function (S^*):

$$\dot{c}(t) = -\left\{j(t) + \frac{\dot{\alpha}(t)}{\alpha(t)} - \pi(t)\right\}.\frac{g'[c^*(t)]}{g''[c^*(t)]} - \frac{\pi(t)}{\alpha(t)}\frac{\beta(t).\varphi'[S^*(t)]}{g''[c^*(t)]} \qquad (31)$$

$$\dot{S}(t) = m(t) - c^*(t) + j(t).S^*(t)$$

Writing the first equation in (31) slightly differently, it is possible to interpret the role of the consumer's bequest to dependants:

$$\dot{c}(t) = -\left\{j(t) + \frac{\dot{\alpha}(t)}{\alpha(t)}\right\}.\frac{g'[c^*(t)]}{g''[c^*(t)]} + \left\{\frac{\pi(t)}{\alpha(t)}\frac{\alpha(t).g'[c^*(t)] - \beta(t).\varphi[S^*(t)]}{g''[c^*(t)]}\right\} \qquad (32)$$

The first term on the right hand side of (32) is equal to the equation without uncertainty about (T), equation (13). The second term, however, if negative, implies that lifetime uncertainty makes the consumer more impatient, and if the second right hand side of (32) is positive then lifetime uncertainty makes him less impatient.[16] The author concludes: "from this it follows that lifetime uncertainty increases impatience at time (t) if $(\alpha(t).g'[c^*(t)] > \beta(t).\varphi'[S^*(t)])$ and decreases it if the reverse inequality holds. In other words, impatience is greater than it would be with no uncertainty if the marginal utility of consumption exceeds the marginal utility of bequests, and it is less than it would be under no uncertainty if the marginal utility of bequests exceeds that of consumption" Yaari (1965).

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[15] But subject to the constraint $c \geq 0$.

[16] Reference to Irving Fisher's term: "Uncertainty of human life increases the rate of preference for present over future income for many people, although for those with loved dependants it may decrease impatience." (I. Fisher, 1930, *The Theory of Interest*, p.216)

The author explores the cases analysed before, A and B, but now in the presence of a life insurance market (cases C and D). The conclusions are presented here but the algebra is suppressed because it shows no additional insights to the analysis. Case C considers that the consumer has no bequest concerns but he or she is constrained by the requirement that his or her transferable assets at time of death should be non-negative with probability equal to one. It is concluded that the introduction of insurance is equivalent to the removal of uncertainty from the problem of consumption allocation. Case D, in which the consumer may have assets or liabilities both in the form of regular notes and in the form of actuarial notes, also has the same solution that holds in the absence of any uncertainty. Another important conclusion states that when the insurance market is available the consumer can separate the consumption decision from the bequest decision.

Yaari's model was innovative while introducing uncertainty to the classical problem of consumption allocation during the consumer's lifetime. However, it does not address directly some concerns of this research, which are the role of age and health status in individual's willingness to pay for a reduction in his or her risk of death. Nevertheless, it is the conceptual basis of further models that explicitly introduces the problem, such as the general life-cycle model of consumption.

3.2.2. The general life-cycle model of consumption: the Shepard-Zeckhauser model

The general life-cycle consumption model explicitly introduced life-risk-mitigating goods or services among the consumption possibilities of individuals faced with the uncertain lifetime consumption modelled by Yaari (1965). That is, in this model the consumer devotes his or her resources either to purchasing reductions in his or her probability of death, or general consuming, constrained by income. By doing this Shepard and Zeckhauser (1982) focused on the way some age-related attributes (mainly income and consumption) could be introduced into a utility function for life. This characteristic allowed the analysis of how individual willingness to pay for a mortality risk reduction relates to individuals' age and income, an important issue for the purposes of this study. Like Yaari (1965), the authors also analysed lifetime consumption under uncertainty in the presence of insurance and capital markets.

Shepard and Zeckhauser (1982) addressed the question of how economists should think about individual purchases of survival, purchases defined as actions or goods to reduce risks of death. In other words, they addressed how to value reductions in risk. The authors suggested three justifications for examining the approaches to this problem:

(i) Economists may better understand the decisions that individuals make when choosing occupations and lifestyle;

(ii) Economists can help people assess their probabilities and value structures in order to make better choices;

(iii) Economists can improve public policies that affect probabilities of death.

They focused their model on the last justification because educating policymakers would provide greater immediate social returns than educating individuals. The individual analysed in Shepard and Zeckhauser's model spends income to purchase probabilities of survival and consumption goods. Many goods, such as food, serve both functions. However, the central concept considered is the willingness to pay for increased survival probability. That is, "how much would an individual threatened with risk of losing his life at some age be willing to pay to reduce the probability of loss? ... Anyone engaged in lifetime consumption allocations must first be concerned with what capital and insurance markets are available for trade. Can he [the average individual] borrow at fair[17] rates against future use? Can he use his wealth to purchase annuities that will guarantee a given consumption level over an unexpectedly long life?" (Shepard and Zeckhauser, 1982)

The authors presented a model to suggest how a rational individual would allocate his or her wealth between buying survival or consumption. In order to facilitate the analysis, they considered three cases; the first two are extreme cases and the third one captures some of the elements of social insurance schemes and, therefore, seems to be more realistic about modern individuals' behaviour:

(i) The "Robinson Crusoe" case in which there are no (insurance) markets on which the individual can trade;

(ii) The case of perfect markets, where individuals can trade across time periods and insure against variability in length of life;

[17] An annuity of one pound is fair when it is expected to have a payoff of $(1+r)$ pounds, where (r) is the risk less rate of interest.

(iii) The pensioner situation, which assumes that the individual has a certain level of consumption that is purchased (per period) at a price guaranteed by the government, and that the price does not vary with his or her survival portfolio over productive and non-productive years. One possible interpretation of the pensioner case would be that all individuals are identical, and that the total product of society is divided among its members. When buying survival, each individual ignores the effect his or her survival will have on the overall level of resources.

The Life Cycle Consumption-Allocation model derives a value function for lives saved as a function of age, giving the value of a life at one age compared with the value at another age, and the trade-off between improved survival and enhanced consumption. The model explicitly treats the dependence of earning rates on age, and treats individual's life cycle savings and consumption as endogenous variables. An important assumption states that an individual's utility over life spans of different lengths can be represented as a weighted sum of period utilities.

Thus, a theoretical limitation emerges from this approach: the value function, which is defined as a weighted sum of period utility functions, is itself a utility function only for small perturbations in the survival function. The reason for the limitation is that decisions must be made before the uncertainty is resolved, so the utility of an attribute in one period depends on the probability distribution of the likely amount of that attribute in a future period.

The authors assume that a consumer maximises his or her expected utility of consumption over an uncertain lifetime subject to wealth and solvency constraints. An individual's lifetime utility is an additive function of his or her period utility functions, referred to by Yaari (1965) as the 'Fisher problem'. The individual's period utility function depends on whether he or she is alive and on his or her rate of consumption in that period, conditional on being alive. This function is scaled so that the period utility of being dead is zero and the utility of consumption is non-negative, monotonically increasing, and risk averse over relevant values of consumption. Like Yaari (1965), section 3.2.1, the period utility function is assumed to remain the same over all periods.

An individual's utility at time t of his or her remaining life after age (t) is given by the expected discounted utility of consumption for each year in which he or she is alive and from time (t) on. Say:

$$y(t) = \int_{t}^{T} \lambda(\tau).u[c(\tau)].e^{-r(\tau-t)}d\tau, \qquad (33)$$

where:

$y(t)$	is the utility of survival at age (t), not conditional on survival at age (t);
τ, t	represents the time in individual's life from 0 to (T);
$l(t)$	is the actuarial survival function that gives the probability of being alive at time (t), ($l(0) = 1$ and $0 \leq l(t) \leq 1$);
$c(t)$	is the rate of consumption at time (t);
$u(t)$	is the period utility function at time (t);

Other notations used below are:

t_0	is the time at which individual first begins to save (accumulate wealth);
$w(t)$	represents the level of wealth at time (t);
$w(t) \geq 0$	is the solvency constraint;
$m(t)$	is the rate of earnings at time (t);
$v(t)$	is the value of remaining life at age (t), not conditional on survival at age (t);
$R(t)$	is the marginal change in optimal ($v(t)$) per unit reduction in the force of mortality at time (t);
$E(t)$	is the discounted expected remaining years of life following age (t) (not conditional on survival at age (t));
c	constant rate of consumption (in perfect market and pensioners case);
H	is the scaling factor for utility function;
$f(t)$	is the net amount received by annuitant alive at age (t);
$N(t)$	corresponds to discounted expected earnings following age (t), discounted to age (t) and conditional on survival at age (t);
$G(t)$	equals to discounted expected consumption following age (t), discounted to age (t) and conditional on survival at age (t);

An important special case, ($y(0)$), gives the utility from the initial age onward, indicating that (33) is a joint utility function for a consumption trajectory and a survival function. Implicit in (33) are some strong assumptions about the multi-period utility function ($u(t)$):

(i) Death has zero utility relative to the utility for being alive with consumption (c). Since no restrictions have yet been placed on the form of scaling of the period utility function, this assumption is relatively benign. Its effect is to require that death cannot have a period utility of negative infinity. That is, this model would not apply if a person would trade off an infinite amount of money for a probabilistic improvement for just an instant more of life.

(ii) The utility of consumption at one time is independent of past consumption (marginality assumption). This assumption implies the additive (integral) form for total expected utility.

(iii) The consumer is assumed to be indifferent to remaining wealth at the time of death (no bequest). This assumption, necessary to keep the mathematics manageable, is plausible under the conditions that the consumer has no economic dependants, or he or she has purchased life insurance to cover the basic needs of the dependants.

The objective is to maximise (*y(0)*) in (33), subject a to feasible trajectory on consumption, which is constrained by non-negativity,

$$c(t) \geq 0 \quad \text{for all.} \tag{34}$$

Shepard and Zeckhauser (1982) started solving the maximisation problem and analysing the first extreme case formulated, namely, the "Robinson Crusoe" case. In this one, the individual cannot borrow against future earnings and no insurance markets are available. Then, the individual faces a solvency constraint on wealth:

$$w(t) \geq 0 \quad \text{for all } t, \tag{35}$$

and an initial condition,

$$w(0) = w_0 \tag{36}$$

It is assumed that when an individual is first able to allocate consumption over his or her lifetime, there is no accumulated wealth (*w(0)=0*). Wealth is related to consumption by:

$$\dot{w}(t) = r.w(t) + m(t) - c(t) \tag{37}$$

In this model, the level of earnings (*m(t)*) depends only on whether the individual is alive at the time (*t*). Equation (37) says that the rate of change in wealth is equal to the interest at rate (*r*) earned on that wealth (assumed to equal the discount rate for future utility) plus earnings less consumption. From the perspective of time zero, the problem comes in maximising (*y(0)*), defined by (33), and subject to (34) and (37).

Assuming that the individual is strongly risk-averse on consumption near zero, the consumer's preferences will keep (*c*) positive and (34) becomes redundant. Two situations are possible: those intervals where the debt constraint is binding ($w(t)=0$) and those in which it is not ($w(t)>0$). The dividing point between these cases is the time (t_0) at which solvency ceases to bind:

$$t_0 = min\{t \text{ such that } w(t)>0\}, \quad t \text{ in } (0, T) \tag{38}$$

The first situation, where ($w(t)=0$) applies for (τ) between 0 and (t_0). To maximise (33), consumption must be raised up to the limit allowed by the solvency constraint, so that ($w(\tau)= 0$) and ($\dot{w}(\tau)= 0$) between (0, t_0). Substituting into (37):

$$c(\tau) = m(\tau) \text{ when } w(\tau)= 0 \tag{39}$$

The second case, where the solvency constraint is not binding ($w(t)>0$), holds for ($\tau > t_0$). Solving it is the equivalent to maximising ($y(t_0)$) subject to (37). The Hamiltonian formed is:

$$H(c,w,\lambda,\tau) = e^{-r(\tau-t_0)}.l(\tau).u[c(\tau)] + \lambda(\tau).[r.w(\tau) + m(\tau) - c(\tau)] \tag{40}$$

Setting the first partial derivative with respect to the control variable of the Hamiltonian to zero:

$$\frac{\partial H}{\partial c} = e^{-r(\tau-t_0)}.l(\tau).u'[c(\tau)] - \lambda(\tau) = 0$$

Solving for the optimal consumption trajectory ($c^*(\tau)$):

$$\frac{du}{dc}|_{c^*(\tau)} = \frac{\lambda(\tau).e^{r(\tau-t_0)}}{l(\tau)} \tag{41}$$

To find ($\lambda(\tau)$), the partial derivative related to the wealth constraint is needed:

$$\frac{\partial H}{\partial w} = \lambda(\tau).r = -\frac{d\lambda(\tau)}{d\tau}$$

Solving the ordinary differential equation:

$$\lambda(t) = \lambda(t_0).e^{-r(\tau-t0)} \tag{42}$$

One interpretation of ($\lambda(\tau)$) is the marginal utility at time (t_0) of wealth at time (τ). Equation (42) indicates that this value is higher in (t_0) and declines from there on at the discount rate. Then, the marginal utility of a unit of wealth at time (t) is proportional to its present value at time (t).

Substituting (42) in (41), for non-binding cases ($c(\tau)$) must satisfy:

$$u'[c^*(\tau)] = \frac{\lambda(t_0)}{l(\tau)} \tag{43}$$

As equation (43) shows, the marginal utility of consumption is inversely proportional to the probability of being alive, resulting in earlier consumption by the individuals, since consumption in a later period involves a greater risk.

Another important result in the "Robinson Crusoe" case emerges when (43) is multiplied by ($l(\tau)$) on both sides:

$$u'[c^*(\tau)].l(\tau) = \lambda(t_0),$$

The result states that the expected marginal utility of consumption is constant for all ages at which the individual is not close to insolvency.

In order to solve (43) for the actual level of consumption, it is necessary to determine the constant ($\lambda(t_0)$). It depends on earnings possibilities and is found by the constraints in wealth, (35) and (36). To use these constraints, the ordinary linear non-homogeneous differential equation (37) is solved and the result is:

$$w(t) = e^{rt}.\int_{t_0}^{t} e^{-r\tau}.[m(\tau) - c^*(\tau)]d\tau, \tag{44}$$

which is the future value at time (t) of the difference between earnings and consumption under the optimal path from time (t_0) to time (t). Since it is not optimal to keep wealth remaining at the maximum possible age, (T), a transversality condition is imposed, ($w(T) = 0$), so that[18]:

$$\int_{t_0}^{T} e^{-r(T-\tau)}.[m(\tau) - c^*(\tau)]d\tau = 0.$$

The value of the remaining life at age (t), ($v(t)$), is necessary to assess the utility of reductions in the probability of death at age (t). The authors show that this value is the same as the utility at age (t) of remaining life beyond age (t) conditional on survival at age (t) for an individual following the optimal consumption pattern. Furthermore, they showed that ($v(t)$) based on the optimal consumption pattern behaves like a utility function for small changes in survival probabilities, ($l(t)$).

In order to formalise the notion of the utility of remaining life, it is important to recall that ($y(t)$ *for* $t\neq 0$) in (33) is the utility at age (t) of all expected years of life beyond age (t). It does not consider the possibility of the individual being dead at age (t). Defining the utility of life following age (t), conditional on survival at age (t), by dividing ($y(t)$) by the probability of survival to age (t), yields:

[18] Remember that one of the (strong) implicit assumptions of this model is that no legacies or bequests values are considered.

$$v(t) = \frac{y(t)}{l(t)} \qquad (45)$$

The probability of death is defined as $\left(\mu(\tau) = -\frac{d}{d\tau}\log l(\tau)\right)$. Suppose there is a small reduction in the probability of mortality at age (*t*), that is, ($d\mu(t) < 0$). It lowers ($\mu(\tau)$) for (τ=*t*), but leaves ($\mu(\tau)$) unchanged for other values of (τ). The new survival function ($l^{\Delta}(\tau)$) is:

$$l^{\Delta}(\tau) = \begin{bmatrix} l(\tau) & \text{for } \tau < t \\ e^{d\mu(t)}.l(\tau) & \text{for } \tau \geq t \end{bmatrix} \qquad (46) \text{ and } (47)$$

For small ($d\mu(t)$), (47) is approximately $[1 + d\mu(t)]l(\tau)$. (48)

The marginal utility at time (*t*), conditional on survival at that time, per unit reduction in the probability of death at time (*t*), is then defined as ($R(t)$). In other words, for a perturbation ($d\mu(t)$), the change in utility is ($R(t).d\mu(t)$). Furthermore, Shepard and Zeckhauser (1982) prove that, in the "Robinson Crusoe" case, the marginal utility of survival probability is equal to the value of remaining life:

$$(R(t)=v(t)). \qquad (49)$$

Willingness-to-pay (WTP) measures how much an individual will sacrifice one desired attribute, wealth for future consumption, in order to obtain improved survival, another desired attribute. A major advantage of Shepard and Zeckhauser's model is that it yields estimates of willingness to pay for marginal changes in the probability of death. To calculate willingness to pay, let ($d\mu$) denote a marginal change in the probability of death and (dw)[19] denote the marginal change in wealth that an individual will accept as compensation to leave his or her overall conditional utility at age (*t*) constant. In other words, (dw) is the willingness to pay for a reduction ($d\mu$) in the probability of death.

Willingness to pay is determined by the indifference relation that the total differential of ($v(t)$) is zero:

$$dv = \frac{\partial v}{\partial \mu} d\mu + \frac{\partial v}{\partial w} dw = 0$$

Using the fact that, in the "Robinson Crusoe" case, the marginal utility of survival probability is equal to the value of remaining life (49) and some substitutions, yields:

[19] The same analysis would be taken with (dc), the marginal change in the rate of consumption.

$$R(t).d\mu + \left[\frac{\lambda(t).e^{rt}}{l(t)}\right].dw = 0 \qquad (50)$$

The term $(R(t).d\mu)$ measures the marginal utility at age (t) of the change in survival, $(d\mu)$, conditional on survival to that age, and the second term is the marginal conditional utility of the change in wealth. The marginal willingness to pay (MWTP) is:

$$MWTP = \frac{dw}{d\mu} = \frac{R(t).l(t)}{\lambda(t).e^{rt}} \qquad (51)$$

In the case where the solvency constraint is not binding, substituting (42) for $(\lambda(t))$ in (51):

$$WTP = \frac{R(t).l(t)}{\lambda(t_0)} \qquad (52)$$

Solving (43) for $(\lambda(t_0))$ and substituting the result into (52) yields:

$$WTP = \frac{R(t)}{u'[c^*(\tau)]} \qquad (53)$$

Equation (53) states that willingness to pay is proportional to the expected utility of remaining life at age (t), conditional on survival at that age, and inversely proportional to the marginal utility of consumption at age (t).

When the solvency constraint is binding, payments to reduce the probability of death must come out of immediate consumption. The indifference relation for willingness to pay is:

$$-R(t).d\mu + u'(c).dc = 0 \qquad (54)$$

Then, marginal willingness to pay becomes:

$$WTP = \frac{dc}{d\mu} = \frac{R(t)}{u'[c(t)]} \qquad (55)$$

Again, willingness to pay is inversely proportional to the marginal utility of consumption on the optimal trajectory, and proportional to the expected utility of remaining life at age (t), conditional on survival at that age. The difference is that in (53) the consumption level is an internal optimum, while in (55) it is determined by the solvency constraint and is equal to earnings, $(m(t))$. This is the main conclusion of the "Robinson Crusoe" case.

Shepard and Zeckhauser (1982) then analysed the second case, namely, the perfect market case. The principal characteristic of the case is the availability of insurance annuities, which offer protection to individuals. Payments are made according to some specified schedule during certain years and the insurer promises to pay some stated income beginning at a specified age and continuing indefinitely. Annuities increase the range of consumption allocations available to individuals and thereby increase their expected utilities of living to any age, and of their remaining life beyond any age.

In terms of the formal model, the availability of annuities replaces the wealth equation (37) by:

$$\dot{w}(t) = r.w(t) + m(t) - c(t) + f(t), \qquad (56)$$

where (*f(t)*) is the net amount received by the annuitant at age (*t*). It is assumed that the annuity is of a type that does not require prepayment; it includes borrowing with a life insured loan; that is, borrowing against human capital during years with low earnings and no wealth. Thus, the assumption of actuarial fairness implies:

$$\int_0^T e^{-rt}.l(\tau).f(\tau)d\tau = 0 \qquad (57)$$

To maximise (*y(0)*) in (33) subject to (34), (35), and (56), the Hamiltonian is formed as in (40), but with the right-hand side of (56) substituting the last term in brackets. The solution involves an optimal consumption path that is a constant rate regardless of age ($\bar{c}$). It is not optimal to hold positive wealth at any age, because the possibility of death means that wealth would become worthless, that is, it is always better to invest the remaining wealth in annuities that would provide a higher consumption rate in case of survival.

With perfect markets, an individual should exchange his or her lifetime wealth for a level lifetime annuity. Consequently, the solvency constraint is binding at every age (*t*), so that (*w(t)=0* for all *t*). Solving (56) for (*f(t)*):

$$f(t) = \bar{c} - m(t). \qquad (58)$$

Thus, the level of the annuity is the deficit in earnings below the constant level of consumption. The authors defined (*E(t)*) as the discounted life expectancy at age (*t*), conditional on survival at age (*t*):

$$E(t) = \frac{1}{l(t)}.\int_t^T e^{-r(\tau-t)}.l(\tau)d\tau. \qquad (59)$$

They defined (*N(t)*) as the discounted expected earnings following age (*t*), discounted to age (*t*) and conditional on survival to age (*t*):

$$N(t) = \frac{1}{l(t)} \cdot \int_{t}^{T} e^{-r(\tau - t)} . l(\tau).m(\tau) d\tau \qquad (60)$$

Substituting (58) and (60) into (57) and rearranging:

$$N(0) = \int_{0}^{T} e^{-r\tau} . l(\tau).\bar{c} d\tau \qquad (61)$$

Equation (61) states that discounted expected lifetime consumption equals discounted expected earnings. Substituting (59) and solving for ($\bar{c}$):

$$\bar{c} = \frac{N(0)}{E(0)}, \qquad (62)$$

which says that the maximum level of consumption is the ratio of discounted lifetime earnings to discounted life expectancy.

Substituting (62) and (33) into (45):

$$v(t) = u(\bar{c}).E(t) \qquad (63)$$

Thus, in the case of perfect markets, the utility of remaining life is equal to the utility of consumption per year times discounted life expectancy.

As in the "Robinson Crusoe" case, Shepard and Zeckhauser (1982) proved that, in the perfect market case, the marginal utility of survival probability (*R(t)*) is the sum of a financial surplus term (a financial effect of a reduction in the probability of death) and a direct utility-gain effect (the pleasure of additional life with quality held fixed):

$$R(t)_{\text{(annuities)}} = u'(\bar{c}).[N(t) - \bar{c}.E(t)] + u(\bar{c}).E(t) \qquad (64)$$

To evaluate willingness to pay in the perfect market case, it is noted that the solvency constraint on wealth is always binding, that is, the individual always spends his or her entire wealth on actuarially fair annuities. Thus, the compensating variations that define willingness to pay are given by (54) and the definition of willingness to pay given in (55). Substituting (64) for (*R(t)*), its value for the perfect market case is:

$$WTP = [N(t) - \bar{c}.E(t)] + \frac{u(\bar{c})}{u'(\bar{c})}.E(t) \qquad (65)$$

The first term is the impact on net lifetime income of improved survival, and the second term is willingness to pay for remaining life at a constant level of consumption. For (*t=0*), the term in brackets vanishes and willingness to pay equals the total lifetime utility of consumption divided by the marginal utility of consumption.

For a more meaningful result, the authors defined the amount of consumption equivalent to the consumer's surplus from being alive in any year with that consumption level as:

$$\bar{c}_s = \frac{u(\bar{c})}{u'(\bar{c})} - \bar{c} \qquad (66)$$

Substituting (66) into (65) yields:

$$WTP = N(t) + \bar{c}_s.E(t) \qquad (67)$$

The first term in equation (67) is discounted expected additional earnings conditional on survival at age (t). The second one is the surplus consumption multiplied by the discounted life expectancy. Thus, livelihood provides a lower bound on willingness to pay, and there is also a consumer surplus from being alive, which is valued by the individual.

Shepard and Zeckhauser (1982) finally turned to the pensioner case, in which readjustments in the rate of consumption are ignored, that is, annuities could not be readjusted. To value the marginal reduction in the probability of death at age (t) in the pensioner case, it is necessary to ignore the first term in (64). Thus,

$$R(t)_{(\text{ignoring readjustments})} = u(\bar{c}).E(t) = v(t) \qquad (68)$$

Willingness to pay is obtained by dividing the utility of remaining life at age (t) by the marginal utility of income. Thus,

$$WTP = \frac{u(\bar{c}).E(t)}{u'(\bar{c})} \qquad (69)$$

Substituting (66) into (69) yields:

$$WTP = c_s.E(t) + \bar{c}.E(t) \qquad (70)$$

In the pensioner case, willingness to pay is the sum of annual consumer surplus (c_s) multiplied by the discounted life expectancy plus average consumption ($\bar{c}$) multiplied by the discounted life expectancy, that is, willingness to pay is the lifetime consumer surplus from being alive plus the discounted consumption.

A major advantage of Shepard and Zeckhauser's model is that it yields estimates of willingness to pay for marginal changes in the probability of death. It provides a mechanism for valuing small changes in risk levels to individuals of various ages, who have particular preferences and earnings opportunities. This mechanism allows analysts to compute the value of individuals' benefits derived from public programmes.

Furthermore, it provides the theoretical basis for many empirical estimates of the value of risk reduction described in the empirical literature review.

- **The role of age in willingness-to-pay measures**

Epidemiologic studies suggest that most of the statistical lives saved by reductions in air pollution levels are those of old people and those with chronically impaired health (e.g. Schwartz, 1994, 2001; Saldiva *et al.*, 1995; Martins *et al.*, 2002; Martins *et al.*, 2004). For this reason, when evaluating the costs and benefits of policies that aim to reduce air pollution, economists must consider how respondents' age and health status affect willingness-to-pay measures.

Concerning the role of age in willingness to pay for improvements in survival, Shepard and Zeckhauser (1982) concluded that it follows an inverted-U pattern related to age. At lower ages, willingness to pay is low because of low earnings and the discounting of years of higher earnings. At older ages, willingness to pay is reduced because of shorter remaining life, since willingness to pay is proportional to the expected utility of remaining life at age (t), conditional on survival at that age. In the case where there was no insurance market, the willingness-to-pay curve followed a pronounced inverted-U, peaking at about age 40, falling by about 50% by the age of 60. With a perfect life insurance market the curve was much flatter but still had a decline of more than 50% between the ages of 40 and 70. It has to be observed that these results were obtained under restrictive assumptions, as described below.

To illustrate their theoretical development, Shepard and Zeckhauser (1982) provided a numerical calculation for a financially self-sufficient individual of 20. They assumed surviving probabilities based on the U.S. male life table, an interest rate equal to 5 per cent, and earnings equal to the average profile from a sample of Social Security enrolees, supposing that earnings ceased at the retirement age of 65. They utilised a constant proportional risk aversion period utility function[20], and empirically observed survival and earning functions for the two polar cases considered in their study: the Robinson Crusoe case and the perfect market case.

In the Robinson Crusoe case, the optimal consumption pattern was identical to the earnings curve from age 20 to 35. Beyond 35 years savings began to accumulate as consumption dropped below earnings. Wealth was equal to zero up to age 35, when it

[20] $u(c) = c^{1-m}$, where (c) is the consumption and (m) the risk aversion parameter, being valued equal 0,8. With this utility function, the utility of zero consumption is set equal to the utility of not being alive.

gradually increased, reaching a maximum at age 65 when earnings ceased. After 65, wealth declined as it started to be depleted by consumption. After some considerations about the discounted remaining consumption function and the remaining lifetime utility, Shepard and Zeckhauser (1982) presented the numerical values for the willingness to pay for reductions in the probability of death. For ages less than 40, willingness to pay was given as equation (55), and for ages beyond age 40 willingness to pay was given as equation (53). In the latter case, the authors found the marginal utility of wealth at age 40 equalled 0.203 by equating (43) and the aversion period utility function. Figure 1 shows the willingness-to-pay estimates as a function of age produced by Shepard and Zeckhauser (1982), for the Robinson Crusoe case.

In the perfect market case, when annuities are considered available, the optimal consumption function was a constant. Since the rate of consumption was constant at all ages, the marginal utility per unit of reduction was the constant multiple, $u'(c)$, times willingness to pay. The authors concluded that annuities made willingness to pay flatter as a function of age. Annuities raised willingness to pay considerably before age 33 and after age 55, but depressed willingness to pay within this high earning interval. Table 2 shows the estimates for selected ages. The results indicate that the availability of perfect markets had different effects on willingness to pay, depending on age. At young ages, when consumers would be limited to their current income, and at advanced ages, when consumers would have very little assets left, perfect markets increase willingness to pay. For mid ages willingness to pay was less because peak consumption was lower.

Figure 1: Willingness to pay as a function of age - Robinson Crusoe case (no annuities available)

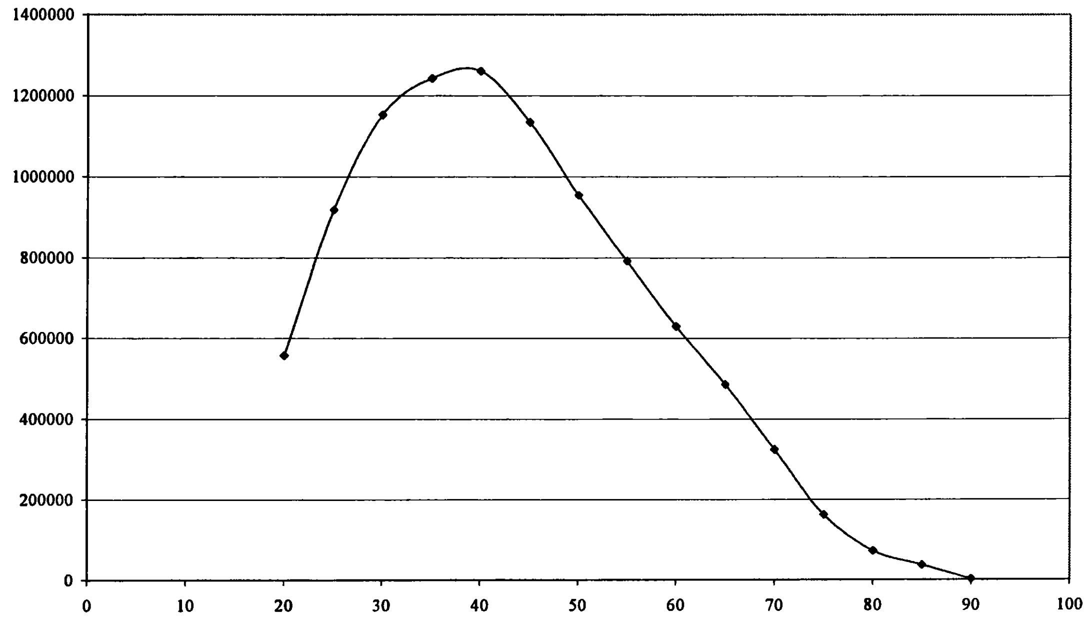

Table 2: Valuations of life at various ages derived from willingness to pay for males with 1978 average income profile – US$ million

Age	Robinson Crusoe case	Perfect market case
20	0.50	1.26
40	1.25	1.15
60	0.63	0.83
80	0.10	0.37

Source: Shepard and Zeckhauser (1982).

3.2.3. Future risks to life: the Cropper-Sussman model

It is widely argued that exposure to air pollution affects human health and can lead to premature death, as summarised in the epidemiologic literature review. The time series medical literature has found a correlation between short-term increases in pollution and specific causes of death, including heart attack, emphysema, and chronic bronchitis (Carrothers *et al.*, 1999). Also, cohort or panel studies suggest that some diseases related to air pollution can cause an increase in probabilities of death in the future, i.e. there may be a time lag between exposure to air pollution and the occurrence of the health effects (latency period). The main examples are carcinogens with a latency period, and the case of pollutants whose effects depend on cumulative exposure, such as particulate matter (Dockery and Pope, 1993; Pope *et al.*, 1995).

Hence environmental economists, when estimating the benefits related to air pollution control programmes, are faced with the task of valuing improvements in exposure to pollutants today that do not reduce risk of death until the latency period. In other words, the benefits in lives saved are not realised at the time that actions are taken. "The benefits of reducing chronic exposure to particulate matter may not be felt immediately, just as the benefits of reducing exposure to carcinogens will not be realised until the end of the latency period" (Cropper, 2000).

The economic literature identifies two approaches to estimating individuals' willingness to pay today for a reduction in risk of dying in the future. The first approach involves asking people directly, through a contingent valuation survey, how much they would pay to reduce their probability of death in a certain point in the future (Krupnick *et al.*, 2000; Alberini *et al.*, 2001; Krupnick *et al.*, 1998). The difficulty with this approach is that considerable resources would be required to obtain reliable willingness-to-pay values for all relevant ages. The second approach involves discounting willingness to pay over the latency period, using an appropriate discount rate (Cropper and Sussman, 1990; Cropper and Freeman, 1991). It relies on obtaining accurate values for willingness to pay at different ages and discounting these estimates back to the present. "The advantage of this approach is that the analyst can use discount rates compatible with other parts of the benefit-cost analysis being performed" (Cropper, 2000).

This section describes the model that Cropper and Sussman (1990) used to demonstrate that individuals discount future risks to themselves at the consumption rate of interest, which equals the market rate of interest in the case of perfect capital markets. Like Shepard and Zeckhauser (1982), the 'life cycle utility model' (Cropper and Sussman, 1990) was developed using the framework of the 'life cycle consumption saving model with uncertain lifetime' (Yaari, 1965). The main differences between Cropper and Sussman's model and that developed by Shepard and Zeckhauser are: (i) Cropper and Sussman analysed changes in future risks of death while Shepard and Zeckhauser investigated current risk of death over the life cycle; (ii) Cropper and Sussman presented a discrete-time version of the life cycle model. Both models investigated willingness to pay for reductions in risk of death with and without the presence of capital and insurance markets.

Cropper and Sussman (1990) assumed that the individual has a probability distribution over the date of his or her death. The expected lifetime utility at age (j), (V_j), is the sum of the utility of living exactly (t-j) more years multiplied by the probability of doing so, assuming that the consumer has no bequest motive:

$$V_j = \sum_{t=j}^{T} p_{j,t}.u_t(c_j, c_{j+1},\ldots, c_t), \qquad (71)$$

where:

V_j	is the expected lifetime utility at age (j);
j	represents the individual's current age;
T	equal to the oldest age to which the individual can survive;
$p_{j,t}$	is the the probability that the individual at age (j) dies at age (t), just before he or she completes age ($t+1$). It follows that $\left(p_{j,t} \geq 0,\ \ t = j, j+1,\ldots, T\right)$ and $\left(\sum_{t=j}^{T} p_{j,t} = 1\right)$;
u_t	is the utility of consumption in years (j) to (t);
$U(c_t)$	is the period utility of consumption, assumed to be increasing in (c_t), strictly concave, and bounded from below;

It is assumed that the utility of consumption is additively separable, implying that equation (71) may be written as:

$$V_j = \sum_{t=j}^{T} (1+\rho)^{j-t} . q_{j,t} . U_t(c_t), \qquad (72)$$

where:

ρ is the discount rate;

$q_{j,t}$ is the probability that the individual survives to age (t), given that he or she is alive at age (j). This is equal to the probability that the individual dies at age (t) or later: $\left(q_{j,t} = \sum_{s=t}^{T} p_{j,s} \right)$;

Equation (72) assumes that the utility of living depends only on consumption and not on length of life, and that survival probabilities are exogenous to the individual. The individual faces the problem of maximising his or her expected lifetime utility from age (j) until (T) by choosing his or her consumption at each age, given his or her initial wealth, (W_j), annual earnings, $(y_t,\ \ t = j, j+1, \ldots, T)$, and capital market opportunities. It is assumed, initially, that the individual can save by purchasing actuarially fair annuities and borrow via life insurance loans. These assumptions are relaxed later in order to evaluate how the capital market imperfections affect the discount rates at which willingness to pay for a future risk must be discounted to the present.

- Actuarially Fair Annuities Case

In the presence of fair annuities, an individual who invests (*$1*) at the beginning of his or her (jth) year will receive (*$(1+R_j)*) at the end of the year with probability ($1-D_j$) and nothing with probability (D_j). For the annuity to be fair (R_j) must satisfy:

$$(1+R_j).(1-D_j) = 1+r, \qquad (73)$$

where

D_t is the conditional probability of dying at age (t). Follows that ($D_T=1$);

$1\text{-}D_t$ is the probability that the individual survives to age ($t+1$), given that he is alive at age (t), that is, $\left(1-D_t = \dfrac{q_{j,t+1}}{q_{j,t}} \right)$;

(r) represents the risk-less rate of interest. Since ($R_j > r$), an individual who can save via fair annuities will prefer to do so. It is assumed that the individual can also borrow at the actuarial rate of interest. The individual's budget constraint requires that the present value of borrowing, discounted at the actuarial rate of interest, equals the value of initial wealth:

$$\sum_{t=j}^{T}\left[\prod_{i=j}^{t-1}(1+R_i)^{-1}\right].(c_t-y_t)=W_j \qquad (74)$$

Equation (74) is equivalent to requiring that the present value of expected consumption equals the present value of lifetime earnings plus initial wealth:

$$\sum_{t=j}^{T}q_{j,t}(1+r)^{j-t}.c_t=\sum_{t=j}^{T}q_{j,t}.(1+r)^{j-t}.y_t+W_j \qquad (75)$$

The pattern of consumption over the lifetime is determined by maximising (72) subject to (75). The correspondent Lagrangian function is:

$$L(c_t,\lambda_j)=\sum_{t=j}^{T}(1+\rho)^{j-t}.q_{j,t}.U(c_t)-\lambda_j.\{\sum_{t=j}^{T}q_{j,t}.(1+r)^{j-t}.c_t-\sum_{t=j}^{T}q_{j,t}.(1+r)^{j-t}.y_t-W_j\} \qquad (76)$$

The first order condition states that:

$$\frac{\partial L(c_t,\lambda_j)}{\partial c_t}=(1+\rho)^{j-t}.q_{j,t}.U'(c_t)-\lambda_j.q_{j,t}.(1+r)^{j-t}=0\text{, or}$$

$$U'(c_t)=\lambda_j.\frac{(1+r)^{j-t}}{(1+\rho)^{j-t}} \qquad (77)$$

Using equation (77) and assuming $(t=j)$, it is observed that the marginal utility of consumption at age (j) equals the marginal utility of income in year (j), that is, $U'(c_j)=\lambda_j$. Combining these results, the optimal path of consumption must satisfy:

$$U'(c_t)=U'(c_j).\frac{(1+r)^{j-t}}{(1+\rho)^{j-t}},\quad \mathrm{t=j+1,\ldots T} \qquad (78)$$

Cropper and Sussman (1990) then analysed how government regulation affects individuals' lifetime utility, by assuming that a government regulation alters the probability that a person dies in any year, given that this person is alive at the beginning of that year. That is, government regulation alters the conditional probability of dying at age (k), (D_k). The authors emphasise that when the conditional probability of death is altered at age (k), it affects the probability of surviving to ages $(k+1)$ and beyond: $q_{j,k+1},q_{j,k+2},\ldots,q_{j,T}$. That follows from the repeated use of the definition of (D_t):

$$q_{j,k}=(1-D_j).(1-D_{j+1})\ldots(1-D_{k-1}) \qquad (79)$$

Formally, the individual's willingness to pay at age (j) for a change in (D_k), $(WTP_{j,k})$, is the wealth that must be taken from him or her at age (j) to compensate him or her for a reduction on the conditional probability of dying at age (k), (D_k), and keep his or her expected utility constant. That is:

$$WTP_{j,k} = -\frac{\dfrac{dV_j}{dD_k}}{\dfrac{dV_j}{dW_j}} dD_k \qquad (80)$$

The first term in the right hand side of (80) is the rate at which the individual is willing to substitute wealth for risk. Using the Envelop Theorem in the Lagrangian function (76) yielded by the maximisation of (72) subject to (75), ($WTP_{j,k}$) can be represented:

$$WTP_{j,k} = \left[(1-D_k)^{-1} \sum_{t=k+1}^{T} q_{j,t}.[(1+\rho)^{j-t}.U(c_t).\lambda_j^{-1} + (1+r)^{j-t}.(y_t - c_t)] \right] dD_k \qquad (81)$$

That is, "willingness to pay at age (j) for a change in the conditional probability of death at age (k) equals the loss in expected utility from age ($k+1$) onward, converted to dollars by dividing by the marginal utility of income in year (j), (λ_j). Added to this is the effect of a change in (D_k) on the budget constraint. A reduction in (D_k) makes the individual wealthier by increasing the present value of his expected lifetime earnings from age ($k+1$) onward. An increase in survival probabilities, however, decreases the consumption that the person can afford in years ($k+1$) through (T), and his or her willingness to pay is reduced by the present value of this amount" (Cropper and Sussman, 1990).

Equation (81) is then used to investigate the relationship between willingness to pay at age ($j=20$) for a change in probability of death at age ($k=40$) and willingness to pay at age ($j=40$) for the same reduction. The authors found that ($WTP_{20,40}$) was equal to ($WTP_{40,40}$) discounted to age ($j=20$), where the rate of discount in each year (t) is the rate at which the individual is willing to trade consumption in year (t) for consumption in year ($t+1$):

$$WTP_{j,k} = \Gamma_{j,k}.WTP_{k,k}, \qquad (82)$$

where the discount factor equals $$\Gamma_{j,k} = \prod_{t=j}^{k-1} (1+R_t)^{-1} \qquad (83)$$

and $$1+R_j=\frac{WTP_{j+1,k}}{WTP_{j,k}}=\frac{U'(c_j)}{U'(c_{j+1})}.(1-D_j)^{-1}.(1+\rho)$$ [21] (84)

Equations (82) to (84) suggest that, if estimates of willingness to pay for a change in conditional probability of death in the future ($WTP_{k,k}$) can be extrapolated using labour market or contingent valuation data, then they can be discounted to estimate willingness to pay today for future risks changes ($WTP_{j,k}$).

➢ No Net-Borrowing Case

Cropper and Sussman (1990) also considered the possibility that actuarially fair annuities are not available, in order to investigate how it would affect the rate at which willingness to pay for a future risk is discounted to the present. The result that willingness to pay for a future risk is discounted at the consumption rate of interest, (84), defined as the marginal rate of substitution between (c_{t+1}) and (c_t) minus one, still holds. The consumption rate of interest, however, exceeds the market rate of interest if the individual's consumption is constrained by income (early lifetime). Supposing that the individual can borrow and lend at the risk-less rate, (r), but constrained by no non-negative wealth at the beginning of each period, implies that the present discounted value of (W_t) must be non-negative for each (t):

$$W_j+\sum_{k=j}^{t}(y_k-c_k).(1+r)^{j-k}\geq 0 \quad \mathrm{j<t\leq T} \tag{85}$$

The correspondent Lagrangian function is:

$$L(c_t,\lambda_j)=\sum_{t=j}^{T}(1+\rho)^{j-t}.q_{j,t}.U(c_t)+\lambda_j.\{W_j+\sum_{k=j}^{t}.(1+r)^{j-k}.(y_k-c_k)\} \tag{86}$$

The first order conditions state that:

$$\frac{\partial L(c_t,\lambda_j)}{\partial c_t}=(1+\rho)^{j-t}.q_{j,t}.U'(c_t)-\lambda_j.(1+r)^{j-t}=0,$$

$$\frac{\partial L(c_t,\lambda_j)}{\partial \lambda_j}.\lambda_j^*=0, \qquad \lambda_j^*\geq 0 \text{ and } \{W_j+\sum_{k=j}^{t}.(1+r)^{j-k}.(y_k-c_k)\}\geq 0 \tag{87}$$

Then, $$U'(c_t)=\frac{\lambda_j}{q_{j,t}}.\frac{(1+r)^{j-t}}{(1+\rho)^{j-t}}, \tag{88}$$

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[21] This can be shown by substituting equation (84) in the optimal path of consumption (89) and assuming ($t=j+1$).

and $$\{W_j + \sum_{k=j}^{t} .(1+r)^{j-k}.(y_k - c_k)\} = 0 \qquad \text{when} \quad \lambda_j^* > 0$$

Using equation (88) and assuming ($t=j$), it is observed that the marginal utility of income in year (j) equals the marginal utility of consumption, that is, $U'(c_j) = \lambda_j$[22]. Combining these results, the optimal path of consumption must satisfy:

$$U'(c^*_t) = \frac{U'(c_j)}{q_{j,t}} . \frac{(1+r)^{j-t}}{(1+\rho)^{j-t}}, \quad t = j+1, \ldots T \tag{89}$$

The resulting willingness to pay for future risk in the no-net-borrowing case is:

$$1 + \delta_j = \frac{WTP_{j+1,k}}{WTP_{j,k}} = \frac{U'(c_j)}{U'(c_{j+1})} .(1 - D_j)^{-1}.(1+\rho) \tag{90}$$

In the case where the wealth constraint is not binding, the consumption rate of interest equals the market rate of interest ($\delta_t = r$) and the discount factor, ($\Gamma_{j,k}$), can be estimated from market interest rates. However, if the wealth constraint is binding, then to obtain discount rates (δ_t) by age is more complicated.

Cropper and Sussman (1990) conducted an empirical simulation using US data on earnings and mortality rates and solving the model for an isoelastic utility function[23]. Table 3 shows the authors' estimates of the rates at which future willingness to pay would be discounted back to age (*18*), under different assumptions about individuals' borrowing opportunities and different ages. These discount factors assume a market rate of interest of (*0.05*) and the US mortality rates for white males.

The authors also inferred the magnitude of ($WTP_{18,k}$) from previous willingness-to-pay estimates to reduce current risk of death by people of different ages obtained by Jones-Lee *et al.* (1985) in a survey conducted in the United Kingdom. The resulting ($WTP_{18,k}$) was obtained by multiplying ($WTP_{k,k}$) by the appropriate discount factor from Table 3. The results shown in Table 4 suggest that, with these assumptions, the willingness to pay at age (*18*) for a reduced probability of death at age (*60*), ($WTP_{18,60}$) is approximately one-twentieth of ($WTP_{60,60}$), the willingness to pay at age (*60*) for a reduced probability of death at age (*60*) discounted to age (*18*).

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[22] In fact, $U'(c_j).q_{j,j} = \lambda_j$. But ($q_{j,j} = 1$) since, by definition, ($q_{j,j}$) is the probability that the individual survives to his (*jth*) birthday, given that he or she is alive at age (j).

[23] $U(c) = c^{0.2}$

Table 3: Discount rates by age, and factors used to discount $WTP_{k,k}$ to Age 18 - US data

Age	No net borrowing case			Annuities case
	Wealth Constraint			
	Binding		Not binding	
(k)	(δ_k)	($\Gamma_{18,k}$)	($[1+r]^{18-k}$)	($\Gamma_{18,k}$)
18	0.124	1.000	1.000	1.000
20	0.119	0.793	0.907	0.904
25	0.106	0.462	0.711	0.701
30	0.093	0.286	0.557	0.545
35	0.082	0.187	0.436	0.424
40	0.050	0.136	0.342	0.328
45	0.050	0.107	0.268	0.253
50	0.050	0.084	0.210	0.193
55	0.050	0.066	0.164	0.144
60	0.050	0.051	0.129	0.105
65	0.050	0.040	0.101	0.074

Source: Cropper and Sussman (1990) – Assuming $\rho = r = 5\%$.
Notes: (ρ) is the individuals' rate of time preference; (δ_k) is the consumption rate of interest; (r) is the market rate of interest; and ($\Gamma_{18,k}$) is the discount factor applied to WTP for a current risk reduction to estimate WTP for a risk reduction in the future.

Table 4: Willingness to pay at age 18 for a reduction in risk of death at Age *k* - the UK survey (Million 1985 US$)

(k)	($WTP_{k,k}$) - US$ ($\Gamma_{18,k}$)	($WTP_{18,k}$) – US$ ($\Gamma_{18,k}$)
18	1.52	1.52
20	1.76	1.21
30	2.04	0.502
40	2.28	0.278
50	1.81	0.190
60	1.60	0.0928

Source: Cropper and Sussman (1990)
Note: $WTP_{k,k}$ is age-dependent WTP for current risk reduction provided by Jones-Lee *et al.* (1985), converted to dollars using 1985 exchange rate (£1 = $1.30). $WTP_{18,k}$ was obtained by multiplying $WTP_{k,k}$ by the appropriate discount factor from Table 3.

3.3. Conclusions

A theoretical literature review was undertaken in this chapter, exploring the different perspectives to establish appropriate economic values for changes in risks of death. The main approaches used to estimate the value of a statistical life were described, namely the human capital approach and the willingness-to-pay approach. Their weaknesses and strengths were discussed and the relevant empirical methods were formalised – the averting behaviour, the 'compensating-wage', the hedonic property value, and the contingent valuation methods.

This chapter provided the basis for the empirical work in Sao Paulo, Brazil, undertaken to estimate the value of a statistical life and the value of a life year lost in Brazil as well as the willingness to pay for a reduction in individuals' risk of death and the impact of age and health status in willingness-to-pay estimates. This empirical study, described in Chapter 5, used the willingness-to-pay approach, the contingent valuation method, and the willingness-to-pay metric. Additionally, most of the issues discussed in this literature review, which are related to the willingness-to-pay approach and the contingent valuation method, were considered in the empirical work (Chapter 5) and also in the discussion of the research questions (Chapter 6).

4. Literature review of empirical studies

Following the theoretical literature review presented in Chapter 3, this Chapter provides a review of the main empirical studies that have estimated the willingness to pay to reduce risks of death or the willingness to accept higher risks and, therefore, the value of a statistical life. This empirical literature review focuses on 'compensating-wage' studies (section 4.1), contingent valuation studies (section 4.2), as well as averting behaviour studies (section 4.3). Section 4.4 discusses some issues involved in risks to life valuations, starting with issues related to the 'compensating-wage' method and then those specific issues regarding the contingent valuation method. The following are discussed: moral and ethical issues involved in risk to death valuation, and how economists deal with altruism when estimating willingness-to-pay measures, a common concern in the air pollution context. Section 4.5 introduces alternative metrics to the value of a statistical life commonly discussed in the medical literature (health indices) and specifically in the context of air pollution (the value of a statistical life year - VSLY). Finally, some conclusions are presented.

4.1. 'Compensating-wage' studies

This section discusses the studies that have used the 'compensating-wage' method and benefits from detailed literature reviews performed by Viscusi and Aldy (2003), Neumann *et al.* (2001), Mrozek and Taylor (2002), Day (1999), and Black *et al.* (2003). Neumann *et al.* (2001) argue that existing literature reviews of the value of a statistical life can be divided in two categories: narrative literature reviews and meta-analyses. The first category involves discussion and synthesis of the trends, arguments, and uncertainties within the literature (e.g. Fisher *et al.* 1989; Miller, 1990, Viscusi, 1993), which consists primarily of a qualitative analysis of the studies, although summary statistics of the value of a statistical life are in general presented. Meta-analysis includes both a narrative discussion of the literature and a quantitative analysis of the value of statistical life estimates, where the value of a statistical life is regressed (dependent variable) against variables that describe the data set analysed and relevant aspects of each study (Neumann *et al.* (2001). Some relevant meta-analysis studies are reviewed below, given that this category of the value of a statistical life literature review is more detailed than narrative studies.

Viscusi and Aldy (2003) have identified more than thirty studies of compensating differentials for risk in the US labour market and another twenty-two outside the US, which included studies of wage-risk trade-offs in labour markets in Australia, Austria, Canada, Japan, and the United Kingdom. In developing countries, the studies focused on Asia: Hong Kong, India, South Korea, and Taiwan. The studies were evaluated according to the sample data used and the risk variable evaluated. The results were summarised by non-US and US-based studies (Table 5).

Regarding the US studies, the authors observed that some of them evaluated the wage-risk trade-off for the entire labour force while others focused on sub-samples for specific occupations, for example police officers (Low and McPheters, 1983). Also, studies were carried out for specific States (South Carolina in Butler, 1983); blue-collar workers only (Dorman and Hagstrom, 1998 and Fairris, 1989); males only (Berger and Gabriel, 1991); and union members only (Dillingham and Smith 1984).

Half of the studies of the US labour market reviewed by Viscusi and Aldy (2003) revealed a value of a statistical life range from US$5 million to US$12 million (2000 dollars). Estimates below the US$5 million value were most frequent among studies that used the Society of Actuaries data[24], which includes workers who have self-selected themselves into jobs that are an order of magnitude riskier than the average (across 37 occupations included in the Society of Actuaries data set, the annual risk averaged approximately 1 in 1000). Studies producing estimates beyond US$12 million used structural methods that did not estimate the wage-risk trade-off directly, or were derived from studies in which the authors reported unstable estimates of the value of a statistical life (Viscusi and Aldy, 2003). The authors estimated that the median value of a statistical life in the US was about US$7 million, which was in line with the estimates from the reviewed studies that they regarded as the most reliable.

Viscusi and Aldy (2003) argued that a relevant research issue of policy importance is the effect of income levels on the wage-risk trade-off. According to the authors, Hamermesh (1999) noted that as wage inequality has increased over time, on-the-job mortality risks have diverged. Hamermesh (1999) concluded that workplace safety is highly income-elastic, which is in line with the findings of Viscusi (1978b) that the value of a statistical life increases with the wealth of the worker. Similarly, Viscusi and Evans (1990) estimated the income elasticity of the value of statistical job injury

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[24] The Society of Actuaries data set provides fatality risk data for 37 occupations for 1967.

risks to be 0.6 to 1.0 in the US. Using meta-analysis of several 'compensating-wage' studies in several countries, Viscusi and Aldy (2003) concluded that income elasticity of the value of a statistical life ranged between 0.5 and 0.6. However, Day (1999) suggested different figures using similar meta-analysis, although the author highlights that his results are dependent on the specification of the meta-analysis model. The figures ranged between 0.36 and 0.55 using a log model – the dependent variable was the natural log of the value of a statistical life, and between 2.65 and 3.56 using a linear model. Neumann *et al.* (2001) suggested in their meta-analysis an income elasticity of the value of a statistical life ranging between 0.86 and 1.3, depending on model specification.

Another point raised by Viscusi and Aldy (2003) was that some studies attempted to explore the effect of occupational diseases, instead of focusing on the risk of accidental death or injuries. For example, Lott and Manning (2000) evaluated the effect of workers' exposure to carcinogen on their wages. Also, Viscusi and Aldy (2003) observed that several early papers in the literature did not find statistically significant compensating differentials for on-the-job mortality risk. As an example, the authors mentioned Leigh (1981), who estimated a risk premium for injuries but not for fatalities; Dorsey (1983) who did not find a mortality-based risk premium; and more recent papers by Leigh (1995) and Dorman and Hagstrom (1998) who also did not find compensating differentials in many model specifications.

According to Viscusi and Aldy (2003), Marin and Psacharopoulos (1982) undertook the first hedonic labour market analysis of job risks outside of the United States in their study of the UK labour market. Based on wage and risk data from the 1970s, Marin and Psacharopoulos (1982) estimated a value of a statistical life of about US$3.5 million. Arabsheibani and Marin (2000) replicated the same analysis for the United Kingdom by employing a similar methodology and more recent wage and risk data from the same sources as in the original study. Arabsheibani and Marin (2000) estimated a higher value of a statistical life than did Marin and Psacharopoulos (1982). While the evaluation of the whole UK labour force yielded a relatively large value of a statistical life of about US$18 million, sub-samples of non-manual workers resulted in the value of a statistical life ranging up to US$68 million. Viscusi and Aldy (2003) concluded that the results from several studies in the UK revealed compensating differentials in the order of 10% of total worker wage income, which are substantially larger than in other developed countries and can be attributed to the correlation between the risk measure and other unobservable variables that may yield important returns to the worker (the issue of unobservables is discussed in Section 4.4.1).

Canadian studies produced compensating differentials more in line with the US experience than with the evidence from the UK labour market (Viscusi and Aldy, 2003). Most Canadian labour market values of a statistical life fell within the range of US$3 – US$6 million. The authors show that with the exception of some UK studies, the compensating differentials estimated in developed country analyses found risk premiums ranging between 1 and 2 per cent of labour income[25], which is a result consistent with the findings of Duncan and Holmlund (1983). These authors estimated a positive wage differential for dangerous jobs on the order of about 2 per cent of wages in Sweden.

Viscusi and Aldy (2003) listed studies in some of the newly industrialised countries of Asia, like Hong Kong, South Korea, and Taiwan. The authors noted that these countries had on-the-job mortality risks three to five times greater than the average in Australia, the US, and the UK. Additionally, the average worker earnings in these Asian countries were two to four times lower than labour earnings in developed countries. For example, Kim and Fishback (1999) studied the South Korean labour market over the 1984 – 1990 period using the unit of observation at the industry level, unlike the studies in the developed countries, which employed worker-level data. Kim and Fishback (1999) estimated the value of a statistical life as approximately US$0.5 million in South Korea, about 94 times the average annual earnings of workers. Similarly, Siebert and Wei (1998) estimated a value of a statistical life for Hong Kong that was even larger than the Korean estimate, and the ratio of value of a statistical life to average annual earnings for Hong Kong was about 150. Viscusi and Aldy (2003) concluded that these estimates are of the same order of magnitude as the ratio observed in the US labour market.

Other studies in Asian countries included Liu, Hammitt, and Liu (1997) and Liu and Hammitt (1999), which estimated the wage-risk trade-off in Taiwan. The first study focused on all non-agricultural workers while the second based their analysis on in-person surveys of petrochemical workers. According to Viscusi and Aldy (2003), workers' risk perceptions in the petrochemical industry yielded a mortality risk rate about 35 per cent greater than the rate published by the Taiwan Labour Insurance

[25] Mean risk levels between 1 in 10,000 and 3 in 10,000 (Table 5).

Agency, the data source used by Liu, Hammitt, and Liu (1997). In addition, petrochemical workers faced higher average mortality risks (perceived and measured) than the average non-agricultural workers in Taiwan. However, the higher wages and income associated with petrochemical workers in 1995 relative to the broader workforce in the early to mid 1980s possibly explains why Liu and Hammitt (1999) estimated the value of a statistical life at about twice the one estimated by Liu, Hammitt, and Liu (1997).

Finally, Viscusi and Aldy (2003) argue that estimates for the Indian labour market produced a value of a statistical life greater than figures for other developing countries despite the fact that per capita, income in India was an order of magnitude smaller than in other developing countries. Shanmugam (1996, 1997, 2000, 2001) estimated the wage-risk trade-off using survey data of manufacturing workers in Madras, India, in 1990. The estimates of the value of a statistical life from these studies in India were very different, even though they reflected the same wage and risk data, which can illustrate how value of a statistical life estimates can be sensitive to different econometric specifications, Viscusi and Aldy (2003) concluded. Table 5 summarises the findings of Viscusi and Aldy (2003).

Table 5: Summary of Labour Market Studies of the Value of a Statistical Life

Author (year)	Sample	Risk Variable	Mean risk	Implicit VSL (US$ million, 2000)
US studies				
Smith (1974)	Current Population Survey (CPS) 1967, Census of Manufacturers 1963, US Census 1960,Employment and Earnings 1963.	Bureau of Labour Statistics (BLS) 1966, 67	0.000125	9.2
Thaler and Rosen (1975)	Survey of Economic Opportunity 1967	Society of Actuaries 1967	0.001	1.0
Smith (1976)	CPS 1967, 1973	BLS 1966, 67, 70	0.0001	5.9
Viscusi (1978,1979)	Survey of Working Conditions (SWC), 1969-1970	BLS 1969, subjective risk of job (SWC)	0.0001	5.3
Brown (1980)	National Longitudinal Survey of Young Men 1966-71, 1973	Society of Actuaries 1967	0.002	1.9
Viscusi (1981)	Panel Study of Income Dynamics (PSID) 1976	BLS 1973-76	0.0001	8.3
Olson (1981)	CPS 1978	BLS 1973	0.0001	6.7
Arnould and Nichols (1983)	US Census 1970	Society of Actuaries 1967	0.001	0.5-1.3
Butler (1983)	S.C.Worker's Compensation Data 1940-69	S.C.Workers' Compensation Claims Data	0.00005	1.3

Low and McPheters (1983)	International City Management Association 1976 (police officer wages)	Constructed a risk measure from DOJ/FBI police officers killed data for 72 cities	0.0003	1.4
Dorsey and Walzer (1983)	CPS May 1978	BLS 1976	0.000052	11.8,12.3
Leigh and Folsom (1984)	PSID 1974; Quality of Employment Survey (QES) 1977	BLS	0.0001	10.1-13.3
Smith and Gilbert (1984, 1985)	CPS 1978	BLS 1975	Na	0.9
Dillingham and Smith (1984)	CPS May 1979	BLS industry data 1976, 79; NY Workers' Comp Data 1970	0.000082	4.1-8.3
Dillingham (1985)	QES 1977	BLS 1976; NY Workers' Compensation Data 1970	0.000008, 0.00014	1.2,3.2-6.8
Leigh (1987)	QES 1977; CPS 1977	BLS	Na	13.3
Moore and Viscusi (1988)	PSID 1982	BLS 1972-1982, NIOSH National Traumatic Occupational Fatality (NTOF) Survey 1980-85	0.00005, 0.00008	3.2, 9.4
Moore and Viscusi (1988)	QES 1977	BLS, discounted expected life years lost; subjective risk of job (QES)	0.00006	9.7
Garen (1988)	PSID 1981-1982	BLS 1980, 81	0.000108	17.3
Viscusi and Moore (1989)	PSID 1982	NIOSH NTOF Survey, Structural Markov Model	0.0001	10.0
Herzog and Schlottman (1990)	US Census 1970	BLS 1969	0.000097	11.7
Moore and Viscusi (1990)	PSID 1982	NIOSH NTOF Survey, Structural Life-Cycle Model	0.0001	20.8
Kniesner and Leeth (1991)	CPS 1978	NIOSH NTOF Survey 1980-85	0.0004	0.7
Gegax, Gerking and Schulze (1991)	Author's mail survey 1984	Workers' assessed fatality risk at work 1984	0.0009	2.1
Leigh (1991)	QES 1972-73, QES 1977, PSID 1974, 81, Longitudinal QES 1973-1977, CPS 1977	BLS 1979, Workers' Compensation data from 11 states 1977-80	0.000134	7.1-15.3
Berger and Gabriel (1991)	US Census 1980	BLS 1979	0.00008-0.000097	8.6-10.9
Leigh (1995)	PSID 1981, CPS 1977, QES 1977	BLS 1976, 79-81 and NIOSH 1980-85	0.00011-0.00013	8.1-16.8
Dorman and Hagstrom (1998)	PSID 1982	BLS 1979-81, 1983, 85, 86; NIOSH NTOF 1980-88	0.000123-0.0001639	8.7-20.3
Lott and Manning (2000)	CPS 1971 and 1985	Hickey-Kearney carcinogenic exposure 1972-74, NIOSH National Occupational Exposure Survey 1981-83	Na	1.5;3.0

Non-US studies				
Marin and Psacharopoulos (1982) UK	General Household Survey 1975	OPCS Occupational Mortality Decennial Survey 1970-72	0.0001	4.2
Weiss, Meier and Gerking (1986) Austria	Austrian Microcensus File of Central Bureau of Statistics 1981	Austrian Social Insurance Data on Job-related accidents 1977-84	Na	3.9-6.5
Meng (1989) Canada	National Survey of Class Structure and Labour Process 1981	Labour Canada and Quebec Occupational Health and Safety Board 1981	0.00019	3.9-4.7
Meng and Smith (1990) Canada	National Election Study 1984	Labour Canada and Quebec Occupational Health and Safety Board 1981-83	0.00012	6.5-10.3
Kniesner and Leeth (1991) Japan	Two-digit manufacturing data 1986	Yearbook of Labour Statistics (Japan)	0.00003	9.7
Kniesner and Leeth (1991) Australia	Two-digit manufacturing data 1984-85	Industrial Accidents, Australia Bureau of Statistics 1984-86	0.0001	4.2
Cousineau, Lacroix and Girrard (1992) Canada	Labour, Canada Survey 1979	Quebec Compensation Board	0.00001	4.6
Martinello and Meng (1992) Canada	Labour Market Activity Survey 1986	Labour Canada and Statistics Canada 1986	0.00025	2.2-6.8
Kim and Fishback (1993) South Korea	Ministry of Labour's Report on Monthly Labour Survey and Survey on Basic Statistics for the Wage Structures	Ministry of Labour's Analysis for Industrial Accidents	0.000485	0.8
Siebert and Wei (1994) UK	General Household Survey 1983	Health and Safety Executive (HSE) 1986-88	0.000038	9.4-11.5
Lanoie, Pedro and Latour (1995) Canada	Authors, in-person survey 1990	Quebec Workers' Compensation Board 1981-85	0.000126	19.6-21.7
Sandy and Elliot (1996) UK	Social Change and Economic Life Initiative Survey (SCELI) 1996	OPCS Occupational Mortality Tables Decennial Supplement 1979/80-1982/83	0.000045	5.2-69.4
Shanmugam (1996/97) India	Authors' survey of blue collar manufacturing workers, Madras, India 1990	Administrative Report of Factories Act 1987-90	0.000104	1.2-1.5
Liu, Hammitt and Liu (1997) Taiwan	Taiwan Labour Force Survey 1982-86	Taiwan Labour Insurance Agency 1982-86	0.000225-0.000382	0.2-0.9
Miller, Mulvey and Norris (1997) Australia	Australian Census of Population and Housing 1991	Worksafe Australia, National Occupational Health and Safety Commission 1992-93	0.000068	11.3-19.1
Siebert and Wei (1998) Hong Kong	Hong Kong Census 1991	Labour Department	0.000139	1.7
Liu and Hammitt (1999) Taiwan	Authors' survey of petrochemical workers 1995	Workers' assessed fatality risk at work 1995	0.000513	0.7

Meng and Smith (1999) Canada	Labour Market Activity Survey 1996	Ontario Workers' Compensation Board	0.00018	5.1-5.3
Arabsheibani and Marin (2000) UK	General Household Survey (1980s)	OPCS Occupational Mortality Decennial Survey 1979-83	0.00005	19.9
Shanmugam (2000) India	Author's survey of blue collar manufacturing workers, Madras, India 1990	Administrative report of Factories Act 1987-90	0.000104	1.0,1.4
Shanmugam (2001) India	Author's survey of blue collar manufacturing workers, Madras, India 1990	Administrative report of Factories Act 1987-90	0.000104	4.1
Sandy, Elliot, Siebert and Wei (2001) UK	SCELI 1986	OPCS 79/80-82/83, HSE 1986-88	0.000038-0.000045	5.7,74.1

Source: Viscusi and Aldy (2003)

Other meta-analysis studies also investigated a range of 'compensating-wages' estimates of the value of a statistical life, associating these estimates with the characteristics of each particular 'compensating-wages' study to propose a range of estimates based on 'good practices'. For example, Mrozek and Taylor (2002) obtained data on 203 estimates of the value of a statistical life from 33 different 'compensating-wage' studies. As a result of the meta-analysis, the authors considered a number of 'best-practice' assumptions regarding methodologies and datasets to recommend a value of a statistical life ranging between US$1.5 and US$2.5 million. Mrozek and Taylor (2002) claimed that an advantage of their value of a statistical life figures is that they were developed using the evidence from the entire literature, not only a few preferred studies or estimates.

In contrast to Mrozek and Taylor (2002), Neumann *et al.* (2001) meta-analysis considered not only the 'compensating-wage' studies, but all legitimate values of a statistical life study identified, including 'compensating-wage', contingent valuation and consumer (averting) behaviour studies based on individual willingness to pay. The authors claimed that by doing so they allowed the statistical analysis to reveal any systematic effects on the value of a statistical life estimates due to inappropriate methodologies or datasets rather than completely eliminating such studies. Another difference of Neumann *et al.* (2001) meta-analysis regards the use of only one value of a statistical life per study, that is, the authors' preferred ones. When the author of a specific study recommended a range of values Neumann *et al.* (2001) used the interval midpoint, resulting in 60 estimates/studies considered suitable for the meta-analysis. Neumann *et al.* (2001) predicted mean values of a statistical life under various assumptions regarding income levels and study type ('compensating-wage', contingent valuation and averting behaviour). The estimates ranged between US$3.4 and US$4.7 million (2001) for consumer market studies; between US$5.6 and US$7.8 million for contingent valuation studies; and between US$7.0 and US$9.7 million for 'compensating-wage' studies.

Day (1999) also performed a meta-analysis of 60 estimates of the value of a statistical life reported in 16 different 'compensating-wage' studies. Using the results of this meta-analysis (a meta-regression), and assuming a preferred specification of the model (assuming a log distribution of the estimates of the value of a statistical life and excluding baseline risk as a covariate) and different 'best-values' for the covariates, Day (1999) presented a 'best' estimate of the value of a statistical life. The estimate, US$5.63 million, was lower than the value of a statistical life estimated at the mean values of the data (US$9.12 million), which lead the author to conclude that the net effect of the biases identified in the estimation of the wage-risk equations was to increase the value of a statistical life. Table 6 summarises the results of meta-analysis studies that suggested values of statistical lives.

Table 6:Summary of meta-analysis studies on the value of a statistical life (US$ million)

Author (year)	Study type used in meta-analysis	VSL (year)
Neumann *et al.* (2001)	Averting behaviour	3.4 – 4.7 (2001)
	Contingent valuation	5.6 – 7.8 (2001)
	'Compensating-wage'	7.0 – 9.7 (2001)
Mrozek and Taylor (2002)	'Compensating-wage'	1.5 – 2.5 (2001)
Day (1999)	'Compensating-wage'	5.6 (1996)

4.2. Contingent valuation studies

Hammitt and Graham (1999) conducted a literature search of willingness-to-pay studies published since 1980. They focused on studies that (i) addressed an intervention designed to protect or enhance human health or safety, (ii) reported willingness-to-pay information elicited using survey methods, and (iii) attempted to link willingness-to-pay responses to specific changes in probability of death, illness, and/or non-fatal injury. The studies reviewed dealt with a large range of risks, from medical treatments to hazardous waste management, the most frequent topic involving traffic safety. None of these studies regarded air pollution reduction programmes and consequent changes in risks of death.

In the context of mortality risk associated with air pollution, some recent studies have used the contingent valuation framework to elicit willingness to pay data for a reduction in risks of death (Krupnick *et al.* 1998, 1999, 2002; Alberini *et al.* 1997, 2001; Cifuentes *et al.* 1999; NewExt, 2002). The common feature of these studies is that they all reject 'compensating-wages' estimates of the value of a statistical life for evaluating risk changes produced by air pollution reduction programmes. The main reason they give is that 'compensating-wage' estimates are measures of compensation received by working-aged individuals for immediate risk reductions whilst, according to the epidemiologic literature, the significant correlation between air pollutants and deaths occurs among people over the age of 65 (Pope *et al.* 1995; Schwartz, 1991, 1993; Schwartz and Dockery, 1992a, 1992b; Gouveia and Fletcher, 2000; Saldiva *et al.*, 1995).

Krupnick *et al.* (1998) presented the preliminary results of a survey instrument developed to fill some gaps in the contingent valuation literature concerning the elicitation of willingness to pay data for a reduction in risk of death. The gaps are related to the internal inconsistency (also cited by Hammitt and Graham, 1999), that is, the way individuals misperceive small changes in their risk of death. The authors believed that part of this misperception is due to the way changes in risk are presented to the respondents, and attempted to develop a survey instrument that introduced basic concepts of probabilities. The first section of this instrument also proposed simple practice questions to familiarise the respondents with the probability concepts introduced. The second section presented leading-age and gender-specific causes of death and introduced common risk-mitigating behaviours, and the third section educated the respondents about the costs associated with risk-mitigating behaviours. The final section elicited information about the willingness to pay for risk reductions of a given magnitude that occur at a specified time.

The willingness-to-pay section of the instrument presented by Krupnick *et al.* (1998) started by introducing a baseline risk specific for the respondents' age and gender. The respondent was then asked to consider two risk reductions occurring over the next ten years: the first risk reduction reduces the baseline risk by 5 in 1,000, while the second change reduces the baseline risk by 1 in 1000. The willingness-to-pay questions were then presented to the respondents for each baseline risk reduction, and finally another willingness-to-pay question was introduced concerning future risk reductions. This last question is specifically important for valuing environmental improvements related to conventional air pollutants and carcinogens, given that the benefits related to the risk reduction involved occurs in the future while the costs of implementing such improvements are incurred in the present (Section 4.4, Future Risks to Life).

The results of the questionnaire pre-tests conducted by Krupnick *et al.* (1998) indicated that individuals were able to distinguish between different magnitudes of small probabilities and also were able to make judgements about future risks. This instrument, or related variations of it, was used to elicit willingness to pay for risk reductions and, consequently, to estimate the value of a statistical life in Canada, Japan, United States of America, Chile, United Kingdom, France, Italy and Spain.

Before describing the study cases, it is worth highlighting the fact that the general models discussed in Chapter 3 provide the theoretical basis for the basic contingent valuation instrument described above; supporting the willingness-to-pay values estimated in the study cases. Specifically, the General Life Cycle model of consumption (Shepard and Zeckhauser, 1982) provides the theoretical arguments involved in the empirical tests of how willingness-to-pay measures for reductions in risks of death vary with age, a common concern of the studies discussed below. Furthermore, the Life Cycle Utility Model (Cropper and Sussman, 1990) is the theoretical reference for the estimation of willingness to pay for a fatal risk reduction at some point in the future.

- **Japan**

Krupnick *et al.* (1999) reported the results of a pilot survey conducted in Tokyo, Japan. Although based on the instrument mentioned in Krupnick *et al.* (1998), this survey instrument incorporated some important improvements. It (i) targeted the 45-75 year old population, (ii) discussed mortality risks in ten-year intervals, (iii) change in risk corresponded to annual risk changes, and (iv) considered the risk reduction as a private good. The first was appropriate considering that the goal of the survey was to discuss reductions in mortality risks in the context of environmental policy, and it is only in middle age that risks of death from cancer, cardiovascular and respiratory diseases become significant. The use of ten-year intervals was important because it allowed risks to be represented in terms of chances per 1000, which can be represented graphically, facilitating the respondents' comprehension of risk concepts. Also, it allowed the assessment of a risk of magnitude similar to that related to air pollution reductions (1 in 10000) in annual risk reductions of 1 in 1000. This increased the general understanding of the risk changes being valued. Finally, the authors considered the method of delivering risk reductions as a private good, that is, not covered by health insurance nor delivered by environmental programmes, which reduced the risk of death for the whole population, not only for the respondent. This feature could make the respondents think of their own risk and avoids the free-rider behaviour[26].

The survey was conducted during February and March 1998 for a total of 316 respondents. Although focused on individuals from 45-75 years, the survey included some individuals as young as 30. The sample selection involved recruiting employees in different companies in Tokyo, and also random selection through telephone calls. Respondents were assigned to two different sub samples, the first one receiving first the willingness-to-pay question related to the 5-in-1000 risk reduction and a subsequent question related to the 1-in-1000 risk reduction; the second sub sample receiving the willingness-to-pay questions in an inverted order. Both groups received a third willingness-to-pay question for a risk reduction occurring between 70-80 years. The willingness-to-pay questions observed the dichotomous choice format with two follow-up questions, and three initial values (bids).

The estimation process of median and mean willingness-to-pay measures combined the responses to the initial and follow-up questions to obtain the lower and upper bounds of the interval of the respondent's willingness to pay. The authors considered that the willingness to pay followed different distributions, such as 'F', Weibull, lognormal, exponential, logistic and log logistic, and estimated the parameters of a maximum likelihood function[27].

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[26] Free-rider behaviour arises when individuals misrepresent their true marginal utility for the provision of a public good. In other words, as the public good will benefit all individuals, the respondent declines a payment considering he or she can free ride on other individuals' payments.

[27] For definitions and details of these distributions, refer for example to Greene (1998). In short, the ratio $F(n_1, n_2) = \frac{x_1/n_1}{x_2/n_2}$ has 'F' distribution with n_1 and n_2 degrees of freedom, assuming that x_1 and x_2 are two independent chi-squared variables with degrees of freedom parameters equal to n_1 and n_2. The lognormal distribution is defined as $LN(\mu, \sigma 2) = f(x) = \frac{1}{\sqrt{2\pi}\sigma x}.e^{-1/2(\ln x - \mu/\sigma)^2}$; the logistic distribution as $F(x) = \frac{1}{1+e^{-x}}$; the Weibull density function is defined as

The results of the Japanese study case were obtained assuming the Weibull distribution of willingness to pay. The authors claimed that their willingness-to-pay measures implied values of a statistical life far lower than those reported by labour market studies, which average around US$5 million. Furthermore, a series of tests were developed to determine the relationship between the willingness-to-pay estimates and different baseline risks, and also between willingness-to-pay measures and other regressors, like dummies indicating whether the respondent took into account altruism when answering the willingness-to-pay questions. Although the authors could not explain it, respondents who took into account effects on other individuals reported lower willingness to pay for a reduction in risk of death. The age effect was consistently positive, which means that older people were willing to pay more for a given risk reduction than younger people.

The main feature of the Japanese study was the improvement made in the survey instrument in order to overcome common problems in contingent valuation studies related to environmental risk reductions, such as future risks to life and communication of small risk changes. The authors developed a survey instrument that focused on mortality risk realised in the future and the questionnaire was administered face to face with extensive use of visual aids, with some cognition tests included in the instrument. The results demonstrated that the instrument was successful in the way that individuals were able to distinguish between different magnitudes of small changes in mortality risks, and between the same changes in risks occurring at different times.

- **Canada**

The Canadian study case had as its main objectives the estimation of what older people were willing to pay to reduce their risk of dying and the examination of the impact of age and current health status on willingness to pay. Krupnick *et al.* (2002) argued that the majority of statistical lives saved by environmental programmes are lives of old people and those with chronically impaired health. Respondents were asked whether they had ever been diagnosed as suffering from several diseases, like cancer and chronic heart or lung diseases. In addition, respondents were asked to complete a

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$f(x) = \frac{\theta x^{\theta-1}}{\rho^{\theta}} \exp(-(\frac{x}{\rho})^{\theta})$; the exponential is $f(x) = \frac{e^{-(x-\mu)/\rho}}{\rho}$; and log-logistic is detailed health questionnaire[28] in order to capture the severity of the disease and other chronic health conditions, physical and psychological. From this questionnaire it is possible to construct physical health scores, such as energy/vitality and general health, and a mental score, which measures symptoms of psychological distress.

The survey targeted people 40 to 75 years old in Hamilton, Ontario, Canada. It was self-administered using a computer by 930 respondents, with the help of audio and visual aids to communicate specific baseline risks of death and the changes in risk. Krupnick *et al.* (2002) used graphs containing 1000 squares to explain probabilities of death, where white squares denoted chances of surviving, red squares represented chances of dying, and blue squares showed reductions in the risk of dying. Also, graphs were used to illustrate the different timing of payments and risk reduction periods. Like in the Japanese case study, a ten-year risk reduction period was used and information was given to respondents about quantitative risk reduction associated with some medical and non-medical procedures, and their relative costs, before asking the willingness-to-pay questions. Respondents were asked if they were willing to pay for an abstract product that would reduce their own probabilities of death during the following ten years, which means that risk reductions were considered a private good.

Median and mean willingness-to-pay estimates were US$253 and US$466, respectively, for the 5-in-1000 risk reduction, and US$131 and US$370 for the 1-in-1000 risk reduction. The results presented by Krupnick *et al.* (2002) indicate that, regarding tests of risk comprehension, 11.5% of the sample gave wrong answers when asked which person had the higher risk of death, after different risks being represented using the visual aid. Also, 13% of the sample gave wrong answers when choosing which person they would rather be, the one with lower risks or the other, and 2.6% of the sample gave wrong answers to both questions. Concerning the understanding and acceptance of the proposed scenario, 20% of the sample did not think that the baseline risk of death given in the survey applied to them. Although 31% of the sample did not believe the abstract product proposed to reduce risks would work, only 20% said this fact affected their willingness to pay.

$$F(x) = \frac{1}{(1+x)^2}$$

[28] Short Form 36, or SF-36. Ware, J.E.Jr., Kosinski, M. and Keller, S. (1997). *SF-36 Physical and Mental Health Summary Scales: a user's guide manual.* Lincoln: RI Quality Metric.

Concerning the willingness-to-pay estimation process, Krupnick *et al.* (2002) used a statistical framework to model willingness to pay based on an interval-data/continuous-data variant of the Tobit[29] model, known as the Spike[30] model. It was justified because of the significant number of zero responses in the sample. The authors assumed a normal distribution for willingness to pay and adapted the Spike model to the sample, which included a mix of zero willingness to pay, continuous observations, and interval data. They also estimated a probit model trying to identify reasons for zero responses to willingness-to-pay questions, but there was no particular association between zero responses and individual characteristics, with the exception of the mental health score. The results showed that people with lower mental health scores were more likely to answer zero to willingness-to-pay questions for the risk reductions.

The authors performed a Wald test to show that mean willingness to pay for a 5-in-1000 risk reduction was statistically greater than the mean willingness to pay for a 1-in-1000 risk reduction, which means that their estimates passed the internal scope test. However, willingness to pay was not proportional to the size of the risk reduction. The respective values of a statistical life were below or equal to the age-adjusted figures commonly used by Health Canada and bellow the official figure used by USEPA.

One interesting result of the Canadian study regards the fact that age had no effect on willingness to pay until the age of 70. That means that mean willingness-to-pay estimates were similar across age groups up to 70 years and were about 30% lower for the group aged 70 or older. Another important result concerns the role of physical health on willingness-to-pay values, which was not significant, with the exception of cancer. However, this last result was based on a small sample and its credibility is supposed to be low. Regarding the role of the mental health score, Krupnick *et al.* (2002) concluded that people with fewer symptoms of psychological distress were willing to pay significantly more to reduce their chance of dying.

- **United States of America**

The results and specifications of the American study case are given in a reference paper comparing the Canadian and American results (Alberini *et al.*, 2001). From this paper, it can be concluded that the survey instrument used to elicit willingness

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[29] Tobin, J. (1958) "Estimation of Relationships for Limited Dependent Variables" *Econometrica*, 26, p.24-36.

[30] Kristrom, B. (1997) "Spike Models in Contingent Valuation" *American Journal of Agricultural Economics*, 79, p.1013-1023.

to pay was identical to that used in the Canadian study, which means that the questionnaire was self-administered on a computer, avoiding possible interviewer bias and allowing the use of individual-specific baseline risks. Furthermore, the same audio and voice aids used in the Canadian study were available in the American study to increase comprehension of risk changes and introduce simple probability concepts. Other similarities involved the use of risk reductions as a private good – an abstract product that reduces each respondent's own risk of death – and the willingness-to-pay elicitation mechanism being a combination of dichotomous choice payment questions with follow-ups, and open-ended questions.

The sample was nationally representative of the US population for gender, age, race and income, recruited through a technology called Web-TV, which involves attaching a special device to individuals' television sets. The respondent could use a remote control device or a keyboard to access the Internet using the television as a monitor. A firm recruited individuals to participate as panel members in exchange for the technology and free Internet access. The original contact and recruitment were done by telephone through random-digit dialling, and 1800 individuals were contacted. Approximately 1200 actually completed the survey. Because respondents in this study participated from their homes, instead of having to travel to a centralised facility like in other studies, it allowed the inclusion of less healthy individuals and people with impaired mobility.

Alberini *et al.* (2001) reported median and mean willingness-to-pay estimates of US$ 350 and US$ 770 respectively for the 5-in-1000 risk reduction; and US$ 111 and US$ 483 for the 1-in-1000 risk reduction. Values of a statistical life results ranged from US$ 700,000 to US$ 4,830,000. The statistical model of willingness to pay used to estimate mean values was an interval-data model based on the Weibull distribution and was estimated using the maximum likelihood method. The mean willingness to pay for the 5-in-1000 risk reduction was statistically different (Wald test) from the mean willingness to pay for the 1-in-1000 risk change. However, the null hypothesis of proportionality of mean willingness to pay with the size of the risk reduction was rejected, again through a Wald test.

One surprising result refers to high mental scores being positively related to the likelihood of having zero willingness to pay for a given risk reduction. The general notion is that increasing one's chance of survival is highly valued when an individual has a positive view of life. The result is surprising because higher mental health scores imply respondents with less psychological distress, thus it would be expected that individuals with higher mental health scores would have a higher probability of stating a positive willingness to pay. Regarding respondents' physical health, although people with a cancer history were numerous, their willingness-to-pay value was not statistically different from that of other respondents. Instead, chronic lung disease and high blood pressure occurrences had a statistically significant effect on willingness-to-pay values. Another important result refers to the absence of an age effect in willingness-to-pay measures. The median willingness to pay for US respondents aged 70 years or older was only 20% lower than that for the younger age group. However, this difference was not statistically significant, contributing to the authors' conclusion that the impact of age on willingness to pay was modest.

- **United Kingdom**

Markandya *et al.* (2003) adapted the computerised survey instrument developed by Krupnick *et al.* (1999, 2002) to estimate the willingness to pay for mortality risk reductions in the UK. A pre-test of the survey instrument was conducted to identify the best way to adapt the survey instrument to the UK context while maintaining its comparability with the other European country studies and those undertaken in Canada and the US. The UK development work consisted initially of a series of ten in-depth interviews with individuals of age 40 and above, and an equal gender split. The original survey instrument was tested and issues of comprehension were identified. A similar procedure was followed in a series of three focus groups comprising eight participants in each group.

The final survey was conducted in 2002 in Bath where thirty-three groups of ten individuals answered the computerised survey instrument, constituting a total sample size of 330 individuals. The survey respondents were recruited by a professional recruitment company and were offered the equivalent of €25 incentive payment for their attendance. The company had the remit to recruit on a stratified random basis a sample that closely matched the socio-economic characteristics of the UK population, the area of recruitment being a 35-km radius around the city of Bath. The company used a mix of recruitment techniques including random digit dialling, in-street recruiting and snowballing. Out of 1350 eligible respondents contacted, 355 were co-operative, and 330 actually attended. Of the 995 that were not co-operative, 560 were not able to travel to the survey centre and 435 did not find the incentive high enough.

The authors claimed that the sample was not fully representative of the population of the UK, however, descriptive analysis showed that the sample had some similar statistics when compared with census data on the UK population. For example, the composition of the sample is relatively even in terms of gender, the median household income was €42,400, the mean household income was almost €44,000, and the respondents had on average 14 years of schooling. Approximately 34 per cent of the sample had (private) health insurance. Virtually all respondents identified themselves as white-Caucasian; thus, no race variables were used in this study. The minimum age of respondents was 40 and the oldest individual in the sample was 77 years old (average age was 58 years). Roughly 45 per cent of the sample was of age 60 or older[31].

Estimates of mean and median willingness to pay were based on a fully parametric model that assumed that willingness to pay follows the Weibull distribution. The willingness-to-pay elicitation format used was the dichotomous choice format with follow-up question, which allows the formation of intervals around the respondent's true willingness-to-pay amount by using the responses to the initial and first follow-up questions. The mean willingness to pay for a 5-in-1000 immediate risk reduction was €736.3, while the median estimate was €387.6. These figures implied a value of a statistical life in the range €772,000-1,472,640.

The validity test performed in the willingness-to-pay regressions examined the effect of various factors on willingness to pay. Focussing on the effect of age on willingness to pay for the 5-in-1000 risk reduction, different functional forms were tried, but no meaningful association between respondent age and willingness to pay was detected. The authors checked if willingness to pay depended on the expected remaining life, and found that the coefficient of the expected remaining life was positive but insignificant. Possible associations between willingness to pay and baseline risk were checked but neither absolute nor proportional baseline risk was significantly associated with willingness to pay, and the coefficient on the former of the wrong sign (negative).

In a specification where age was controlled using age dummies, and individual characteristics of the respondent were added, higher education levels were associated with lower willingness-to-pay amounts. This effect was also observed in the Canadian and US studies, although it was not statistically significant. Income per household

[31] According to the UK Office for National Statistic (Focus on People and Migration, June 2004), the age structure in England in 2002 was as follows: 20% between 0 and 15 years old; 64% aged between 16 and 64, and 16% older than 65 years.

member was positively and significantly associated with willingness to pay. In general, the health status did not matter, although the coefficient of the dummy variable indicating the presence of chronic illness was positive and significant at the 5% level. The coefficient of this dummy was 0.18, implying that suffering from any of the cardiovascular, lung or blood-pressure illness, or having had a stroke, tends to raise willingness to pay by about 20 per cent in the UK.

Regarding willingness to pay for a future risk reduction, the authors found that it tended to increase with the (log) chance of surviving to age 70 and to decrease if the individual thought his or her health would be worse in the future. Other variables did not matter, with the only exception of the presence of chronic illness among relatives.

- **France**

Desaigues *et al.* (2003) described the application of the questionnaire of Krupnick *et al.* (1998, 2000) in France. The original questionnaire was administered to 299 individuals, but in contrast to the UK and Italy, an open question was added after each set of bids; at the end of the questionnaire the willingness-to-pay values were recalled to give the respondents the opportunity to correct their values. In addition several variants were tested on samples of about 50 each, in particular variants phrased in terms of life expectancy gain. From the total sample, 151 answered the sequence S1 (first 5-in-1000 then 1-in-1000 risk reduction) and 148 answered the sequence S2 (first 1-in-1000 then 5-in-1000).

Interviewees were recruited by a private marketing firm, using the French quota system to be representative, in age, sex and income, of the population of Strasbourg. They were paid €20 to attend the interview. It was observed that 269 individuals (90%) had private health insurance to supplement the social security system. 51% of the sample thought that their health was comparable to the rest of their age group, 38% that it was better than the rest of their age group, and 11% that it was worse. The authors claimed that the respondents had trouble understanding probabilities (23% failed the first probability test, 22% chose the wrong person in the second probability test and the wrong person in probability choice) but learnt fast to correct their answer. 18% of the respondents acknowledged a poor comprehension of probabilities.

Regarding the different sequences of risk reduction presented to respondents, S1 and S2, the authors concluded that the second wave showed a higher number of zeros. This suggests that the mental exercise seems to be more difficult. The starting probability reduction (1 in 1000) was perceived as too low; respondents who stated a positive willingness to pay could not increase their willingness to pay for a 5-in-1000 risk reduction, correcting more often the first stated value. The ratio (willingness to pay for 5-in-1000)/(willingness to pay for 1-in-1000) was 1.6 for S1, and 1.2 for S2. The starting risk reduction also had a large impact on willingness-to-pay estimates, on average the positive willingness to pay were FF 1022 larger when the starting risk reduction was 5-in-1000 rather than 1-in-1000.

To test the sensitivity of the results to the commodity proposed, to the elicitation question, and to the risk reduction, the authors carried out several variants on samples of about 50 individuals each. Variant 1 treated the air pollution problem as a public good, that is, the good to be valued was described as a public health policy instead of a product (or treatment). Only one bid was offered (1000 FF) in this variant due to the small size of the sample (52 individuals), followed by an open question. The payment vehicle was an increase of the social security contribution, which is deducted from the salary and collected and administered by a public agency. Mean willingness to pay was lower than that for the original questionnaire, by a factor of about 2. However, the credibility of the scenario was enhanced. For example, only 17% of the respondents doubted the effectiveness of the public policy (compared to 37 % for the product), and 90% took into account their budget constraint (compared to 76 % for the product). The number of zero willingness to pay was lower - 12 % (8% in S2 and 15% in S1), but 60% thought of other benefits (mostly for society in general), compared to 26 % for the product.

Variant 2 tested the open question elicitation format without previous offered bids. This version was applied to a sample of 50 individuals answering the S2 sequence (1-in-1000 followed by 5-in-1000). Variant 3 used life expectancy instead of risk reduction as the good being valued. This variant was tested in three versions. First, only a gain in life expectancy was stated (an indefinite extension of life), with a proposed bid of FF 1000 (59 individuals). Second, a further variant asked 61 respondents to give their willingness to pay for an increase in life expectancy of 1 month, 3 months, and 12 months. Third, the risk reduction was stated as in the original questionnaire and then translated to the individual life expectancy gain (calculated by the computer in response to the age and gender of the individual). The results of the last 2 versions are not comparable because the life expectancy gain was put into perspective by telling each respondent his or her life expectancy, without any reference to the corresponding risk reduction.

The authors concluded that the better the scenario was understood and accepted, the lower was the highest individual willingness to pay. In the original version the highest willingness to pay for the open question and the 5-in-1000 risk reduction was about FF 6000. When the bids were removed and only the open question was asked, the highest willingness to pay was FF 3650. In the life expectancy variants it fell to FF 1800 for version (i) and FF 1500 for version (iii). For version (ii), willingness to pay increased with life expectancy: FF 140 for 1 month, FF 234 for 3 months, FF 377 for 12 months. Finally, the authors recommended a range of value of a statistical life ranging from €0.5-3 million from the French survey, with a central value of €1 million[32].

- **Italy**

Alberini and Scarpa (2003) summarised the results of a contingent valuation survey eliciting willingness to pay for reductions in individuals' own risk of death. The survey was self-administered using the computer to a sample of respondents recruited at various locations in Italy. Again, the original questionnaire was that developed by Krupnick *et al.* (1998, 2000) and was translated into Italian. The objectives of the study included investigating if the willingness to pay for a reduction in the risk of dying depended on age. Also, testing if willingness to pay was influenced by a person's health status, and testing if it was possible to elicit meaningful willingness-to-pay figures for a latent risk reduction. Finally, exploring the issue of transferability of willingness to pay figures from one country to another, by comparing obtained results with the UK and French results.

Respondents were selected among participants in computer classes at the Fundazione Eni Enrico Matei - FEEM's Multimedia Library in Venice, Milan, Turin and Genoa, and from workers of the Milan area for a total of 292 completed interviews. The objective of the sampling was to obtain a random sample stratified by age and gender. The age brackets were 40-50, 51-60 and above 60. Approximately one third of the sample was assigned to each stratum with an even split between men and women. Sampling took place in two waves. The first wave involved the collection of the first 155 completed surveys and took place in different cities (Venice, Milan, Genoa and Naples). The sampling method was based on convenience sampling as people who took part into information technology priming classes were asked to fill in the survey in various centres. The second wave was designed to complement the first in terms of achieving the target numbers in each age/gender category, and was carried out in Milan and surrounding areas by enumerators that carried out surveys on laptops.

As in the UK and French contingent valuation studies, respondents were asked to think about a product that would deliver the stated risk reduction, and were asked whether they would buy the product at the stated price, with payments to be made every year for 10 years, beginning immediately. The risk reductions to be valued by the respondent were private, and the elicitation technique was dichotomous choice with one dichotomous-choice follow-up question. Respondents were asked several questions about their own health status. For example, how they would rate their health, relative to others of the same age. About 42 per cent of the sample rated their health as excellent or very good when compared with others the same age. This figure is comparable to the corresponding proportion in the French study, but is much lower than the corresponding statistics for the UK, Canada, and the US.

Respondents were also asked whether they suffered from various chronic ailments. The authors founded that about 15% had heart disease, 13% had a chronic respiratory illness, 33% had high blood pressure, and less than 7% had or have had cancer. In the survey, respondents were told the risk of dying over ten years for the average person of their age and gender. The average baseline risk in the sample was about 50 per 1000, and was much lower than the baseline risks for the UK, France, the US and Canada.

Finally, mean willingness to pay for the 5-in-1000 risk reduction was about twice the mean willingness to pay for the 1-in-1000 risk reduction. Median willingness to pay for the 5-in-1000 risk reduction was 2.34 times the median willingness to pay for the 1-in-1000 risk reduction. To compute the value of a statistical life implied by the willingness to pay figures, the authors divided willingness to pay by the annual risk reduction, assuming that the risk reduction over the course of 10 years would be accrued uniformly. A total of four possible values were produced, one for each of mean and median willingness to pay, and one for each of the two risk reductions. The value of a statistical life ranged from €1,448,000 to €2,896,000. The mean willingness to pay for a

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[32] FF1 = €0.15 (Desaigues *et al.*, 2003)

risk reduction of 5-in-1000 at age 70 was estimated at €557.63, and median willingness to pay for the same risk reduction was €225.95.

The authors concluded that the Italian data satisfied the internal scope test and indicated that willingness to pay depended on gender and income. Additionally, at least when the willingness-to-pay responses for the 5-in-1000 and 1-in-1000 risk reductions were pooled to increase the sample size, willingness-to pay estimates suggested that the relationship between age and log willingness to pay was an inverted-U.

- **Europe (Pooled data the UK, France and Italy)**

Alberini *et al.* (2004a) and EC NewExt (2003) estimated willingness to pay and value of a statistical life for Europe obtained by using the pooled data of the three studies described before – the UK, France and Italy. The authors used the responses to the willingness to pay questions about the immediate risk reduction to estimate the value of a statistical life. They showed that the estimates of the value of a statistical life were within (and on the lower end of) the range recommended by DG Environment and US EPA, but did not find any evidence that willingness to pay and value of a statistical life were lower for older individuals. Willingness to pay showed good internal validity in the sense that it depended on income and on the fact that the respondent had been admitted to the hospital or had visited an emergency room for cardiovascular or respiratory illnesses in the last five years, among other things.

The average age of the respondent was 55 to 58, depending on the country. The samples were relatively well balanced in terms of gender, with only a slight prevalence of women over men. The average number of years of schooling ranged from 11 (for the French study) to about 14 (for the UK sample). The percentage of the sample that rated their own health as good or excellent relative to others of the same age varied across the three countries. In Italy, only 38 per cent of the respondents described their health as very good or excellent, against 61 per cent of the British sample. The percentages of respondents who failed the probability tests or otherwise reported having problems understanding the concept of risk were similar across the three countries. These percentages were low, suggesting that most people were able to answer the questions meaningfully in the survey.

The unconditional willingness-to-pay model implied a mean willingness to pay US$1,230 (€1,129)[33] per year for the three European countries, and median willingness to pay US$573 (€526) for a 5-in-1000 risk reduction. This implied the value of a statistical life ranging between US$2,460 (€2,258) and US$1,146 (€1,052) million, respectively[34]. The validity test of willingness-to-pay estimates was performed with the usual socio-economic variables. Willingness to pay declined only for the oldest respondents in the sample, who held willingness-to-pay amounts that were approximately 25% lower than those of the other respondents. However, the coefficient on the dummy for a respondent who is 70 or older was not significant at the conventional levels, a similar result found in Canada and US studies (Krupnick *et al.* 2001 and 2002). Men had slightly lower willingness to pay and so did people with higher levels of education, although these effects were not significant at the conventional levels. The presence of cancer and chronic illnesses did not influence willingness to pay, but individuals who had been hospitalised for cardiovascular or respiratory illnesses over the previous 5 years had willingness-to-pay amounts that were over twice as large as those of all others.

The authors also used the responses to the willingness-to-pay questions, combined with the extension in life expectancy implied by the 5-in-1000 risk reduction, to estimate the value of a gain in remaining life expectancy. They used two alternative approaches. The first approach regressed willingness to pay on the gain in the life expectancy based on population life-tables; that is, the baseline life expectancy was the population's life expectancy based on age and gender[35]. This approach resulted in no statistically significant association between willingness to pay and the change in life expectancy. As an alternative, the authors divided willingness to pay by the life expectancy extension to obtain willingness to pay for each month of life expectancy extension. This resulted in mean willingness to pay at US$1,146 (€1,052) per year for each month of additional life expectancy, and median willingness to pay at US$506 (€465) per year. The implied values of a statistical life year (VSLY, discussed in section 4.5) were US$136,438 (€125,250) and US$60,784 (€55,800), respectively. Regarding the effect of age, willingness to pay per month of life expectancy gain was higher

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[33] US$ 1 = € 0.918 (Alberini *et al.*, 2004a).

[34] VSL = mean or median WTP / risk reduction.

[35] The 5 in 1000 over the next 10 years risk reduction equals from 0.64 to 2.02 months life expectancy extension, depending on the person's age and gender, and averaged 1.23 months for the sample.

among older persons, which suggested that the marginal utility of life expectancy extensions increased with age.

The second approach used the "gain in life expectancy" as the respondent's own estimate of life expectancy (respondent's subjective remaining life years). Willingness to pay increased significantly with subjective life expectancy gains, and this increase was less than proportional to such gains. Regarding the possible effect of age, there was little evidence that willingness to pay varies with age, but the regression results suggested a possible inverted-U shaped-relationship. As before, while the presence of chronic illnesses did not affect willingness to pay, having been to the hospital for cardiovascular or respiratory illnesses in the previous 5 years raised the willingness to pay significantly. Willingness to pay for a month of subjective life expectancy gain was US$1,289 (€1,183) and median willingness to pay was US$528 (€485) per year, which resulted in VSLY estimates equal to US$154,684 (€142,000) and US$63,399 (€58,200), respectively.

The authors concluded arguing that their results for extensions in life expectancy should be interpreted with care since their respondents were not asked directly to value a gain in life expectancy. In contrast, it has been indirectly inferred the value of such a life expectancy extension from respondents' willingness to pay for a reduction in their risk of dying.

- **China**[36]

Zhang (2002) reported the results of a survey with Beijing residents and workers in 1999. The objective of the survey was to estimate individuals' willingness to pay for a reduction in their risk of dying. The questionnaire was divided into four parts. Part I asked about the major environmental factors affecting the respondent's health, and occurrence of diseases in the past year. Part II asked if the respondent had health insurance and, if so, which type of health insurance. The respondent was asked to indicate, in case of a job change, his or her preference between a high-risk-highly paid job and, alternatively, a job with low risk and low wage. Part III elicited willingness to pay for risk reductions of a given magnitude, either 2-in-10000 or 27-in-100000. Part IV elicited personal information, including age, gender, education, and income.

[36] Another study is currently being undertaken in China using the Krupnick *et al.* (1998) methodology and supported by the World Bank; no results were available to be included in this literature review. In addition, similar study was carried out in South Korea but no publication was available to provide details of this study.

Over 95% of the respondents were young – i.e. aged less than 45 years. Almost all respondents (99%) had graduated from high school, and had stayed in school at least 11 years. Most of the respondents were teachers (28.5%) or managers (19.6%). Over 30% of the respondents' incomes were greater than 1,000 RMB yuan per month, and over 93% of the respondents' incomes were greater than 500 yuan per month, while average wage in Beijing was approximately 700 yuan per month according to official data. 53% of the respondents or their family members suffered from respiratory or heart diseases. About 70% of the respondents reported having health insurance.

The author estimated parametric and non-parametric mean willingness-to-pay estimates. For a 2-in-10000 risk-reduction, it ranged between 109 and 186 yuan (1999 RMB) and for 27-in-100000 the range was between 261 and 459 yuan (1999 RMB). The corresponding value of a statistical life in Beijing was between 0.5 million yuan to 1.7 million yuan (1999 RMB yuan), equivalent to US$60,000 - US$200,000. To analyse the relationship between income, age, gender, education and willingness to pay Zhang (2002) estimated several models in which willingness to pay was regressed on these socio-economic variables.

Zhang (2002) acknowledged several limitations in his study. First, the sample was not representative of Beijing residents – the results referred to young people in Beijing, the survey just focused on lower income individuals, the respondents had intermediate education backgrounds. Second, the survey did not use audio-visual aids to communicate baseline risk of death and risk change, as suggested in previous studies (Krupnick *et al.* 1999; Alberini *et al.* 2001). Baseline risk was explained in a sentence in the questionnaire. The author concluded that some individuals might find it easier to think about mortality risk reduction in terms of increases in life expectancy rather than as small reductions in mortality risks.

- **Chile**

Cifuentes *et al.* (1999) estimated the value of a statistical life for Chile using the contingent valuation method in order to provide the government agencies with a more accurate value than that commonly used in Chile (US$60,000). This commonly used value was estimated using the human capital approach, which underestimates the value of a statistical life by not considering the individual's wellbeing. The main motivation of the study was the observed big difference between the Chilean value of a statistical life and the American commonly used values (US$450,000 – US$5,000,000). The difference persists even after taking into account the differences in per capita income between the countries and the increasing importance of the value of a statistical life in public policy decision-making.

The survey instrument used in the Chilean study was based on the instrument developed by Krupnick *et al.* (1998), although adapted for Santiago, Chile. The respondents were first informed of the average mortality rates of Santiago, showing them the mortality risks for the following ten years according to their gender and age group. They were asked if they believed that the risk of death showed to them could reasonably be their own, and were given the opportunity to correct it. Respondents were then asked the willingness-to-pay question for a reduction in risk by 1-in-1000. The process was repeated for a different change in risk (5-in-1000) and for a change in risk in the future.

A pilot survey and a pre-test were conducted with 25 and 28 respondents, respectively, all of them final year students of Civil Engineering in the Catholic University of Chile. The pilot survey objective was to test different payment vehicles; annual and monthly payments. The argument was that most payments in Chile are expressed monthly and it would be easier for Chileans to think on the values they would pay for a risk reduction. Most of the surveys reported in the literature, the authors argued, use annual payment. The objective of this test was to validate the instrument and obtain the range of values for the dichotomous choice questions.

The results of the pilot survey showed, according to the authors, that willingness to pay obtained by monthly payment had less dispersion than that obtained with annual payments. The implied value of a statistical life based on median willingness-to-pay estimates ranged between US$310,277 (5-in-1000 risk reduction) and US$413,703 (1-in-1000 risk reduction). Although the preliminary results of the pre-test presented by Cifuentes *et al.* (1999) were based on a sample of only 28 individuals, the authors highlighted some important conclusions. The first one relates to the fact that people were able to identify the difference between the two risk reductions, although the difference was small. The second conclusion was that the estimated value of a statistical life represented approximately 5 times the value obtained using the human capital approach in Chile.

- **United Kingdom**

Chilton *et al.* (2004) estimated the willingness to pay for health benefits associated with reductions in air pollution in the UK. The study aimed to generate a range of monetary values for various key benefits associated with reductions in air pollution levels. The study focused on two types of mortality effects – chronic (loss of life expectancy in normal health) and acute (loss of life expectancy when elderly and in poor health). It focused on two types of morbidity effects; a hospital admission with breathing difficulties, and breathing discomfort on 2 or 3 days every year.

The authors used a contingent valuation survey to elicit the various willingness-to-pay estimates. The principal research tool was a questionnaire administered to a representative sample of the general population. According to the authors, a substantial period of time was spent developing and piloting the questionnaire in collaboration with specialists. The pilot involved conducting a large-scale field test of the questionnaire and happened in Edinburgh and Norwich. The main survey aimed to interview a larger, representative sample of the UK population. It was conducted in 41 different postcode sectors in England, Scotland and Wales. The study used a random probability sampling method involving 2 stages. After stratifying by region and socio-economic status, 41 postcode sectors were randomly selected, and later 35 addresses were randomly selected within each sector, totalling 1435 addresses in the UK. Within each selected household, an individual aged 18 or more was randomly selected. The final sample had 665 interviews.

Interviews were conducted on a one-to-one basis in respondents' own homes, by a team of 48 experienced interviewers using a structured interactive programme on laptops with interviews lasting, on average, 29 minutes. The initial stage of the questionnaire asked respondents general questions about their household. In one of the opening questions, respondents were asked to consider a wide range of different public health risks (of which air pollution was just one) and were asked to consider the three biggest threats to their own health. The reason for this approach was to investigate to what extent respondents identified air pollution as a high priority concern for them, and to put air pollution in some context. The following section of the interview asked the respondent to consider various ways that air pollution might affect people's health, including the impacts on mortality (chronic and acute) and morbidity (respiratory hospital admissions and days of breathing difficulties)[37].

[37] Descriptions of the health impacts were developed in consultation with the Department of Health, UK to provide a brief description as accurate as possible based on current epidemiologic evidence.

The remaining set of questions focused on eliciting willingness to pay for four possible benefits associated with reducing air pollution. Chronic mortality (N) – X months more life in normal health; acute mortality (P) – X months more life in poor health; respiratory hospital admission (H) – avoiding an admission to hospital with breathing difficulties; and days of breathing discomfort (D) – avoiding 2 or 3 days of breathing discomfort every year. In the case of N (X months more life in normal health) and P (X months more life in poor health when elderly) the value of X was randomly set at either 1, 3 or 6 months. Varying the length of the gain in life expectancy provided the possibility of testing sensitivity to scope.

Before getting to the willingness-to-pay questions respondents were encouraged to think about their budget constraint and disposable income. They were told to focus just on the benefits to them personally and the other named members of their household and not to answer on behalf of anyone else. Respondents then embarked on a random card sorting procedure to help them identify the most they would be willing to pay each year for the rest of their lives to get all four of the benefits. This procedure involved the interviewer shuffling a pack of 12 cards showing different amounts. The cards were turned over one at a time and for each in turn, the respondent was asked whether or not it would be worth paying that amount every year for the rest of their life for all four benefits. Each time a card was shown the interviewer provided the respondent with an estimate of how much it would add up over the rest of their life based on the average for someone of their age and gender. Respondents were then asked to divide this maximum total willingness-to-pay amount among the four benefits.

148 respondents were excluded because of protest behaviour or declining to state a willingness to pay. Another 46 respondents gave zero willingness-to pay responses for non-protest reasons. Chilton *et al.* (2004) concluded that chronic mortality was the most valued of the four benefits with, on average, 44.9% of the total willingness-to-pay amount allocated to this benefit, with only 17.4% of respondents assigning no value to this benefit. This contrasted with acute mortality, which was the least valued of the four benefits, with respondents allocating an average of 10.1% of their total willingness-to-pay amount, and more than half of them (52.8%) assigning no value to it at all. The other two benefits, hospital admission and days of breathing difficulties, were allocated intermediate proportions of the total (23.0% and 22.5%, respectively) and were assigned no value by about a third of respondents (31.3% and 36.0%).

The authors claimed that, when allocating their willingness-to-pay amounts between the four benefits, respondents were sensitive to the nature and the quality of the good being valued. In particular, they valued a gain of life expectancy in normal health more highly than a gain of life expectancy in poor health. However, there was no great difference between mean values for willingness to pay for chronic mortality for 1, 3 and 6 months. Parametric estimation of willingness to pay for 1, 3 and 6 months was, respectively, £23.30, £29.61 and £34.40. These values were smaller than the trimmed mean willingness-to-pay values (£60.15, £67.72 and £80.87). However, the authors claimed that the purpose of the regression analysis was principally to examine whether responses moved in the direction suggested by economic theory, and suggested using the trimmed mean willingness-to-pay estimates. The authors' best estimate of the value of a statistical life year (VSLY), based on life extension in normal health, ranged between £31,200 (US$50,856)[38] and £8,000 (US$13,040). In the case of willingness to pay for acute mortality, neither the number of months nor the level of income had any significant impact. The authors argue that there was considerable ambivalence about whether this was considered as a 'good'. For willingness to pay for hospital admission it seems to present an inverse relationship with age.

- **Other studies**

Other contingent valuation studies estimated the value of a statistical life in a number of circumstances. For example, Johannesson and Johansson (1997) attempted to measure the value that adult Swedes place on an increased survival probability at high ages. They estimated the willingness to pay for a programme that would increase the expected length of life by one year, conditional on having survived until the age of 75 years. The authors provided a rough estimate of the value of a statistical life by multiplying the willingness to pay for an extra year of life by the expected duration of a life. It ranged between US$70,000 and US$130,000 (1995). Also, Buzby *et al.* (1995) estimated the value of a statistical life (US$4.1 million 1993) from the willingness to pay for a reduction in risk of cancer from pesticides. Hammitt and Graham (1999) conducted telephone surveys to elicit the willingness to pay for a risk reduction of dying in a car crash. The implied value of a statistical life ranged between US$0.8 and US$2.1 million (1999).

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[38] £ 1= US$ 1.63 in June 2003 (www.xrates.com).

- **Summary**

Table 7 summarises the results of the contingent valuation studies using the Krupnick *et al.* (1998, 1999, 2002) methodology, which aims to facilitate comparison with the figures obtained in the empirical study in Brazil.

Table 7: Summary of annual willingness to pay (WTP) for an immediate risk reduction and the implied value of a statistical life (VSL) – US$

Country ($year)	(WTP)		(VSL)		Annual household income (sample)	
Risk reduction	Median	Mean	Median WTP	Mean WTP	Median	Mean
US ($2000)					55,000	53,000
5-in-1000	350	770	700,000	1,540,000		
1-in-1000	111	483	1,110,000	4,830,000		
Canada ($2000)					50,000	46,800
5-in-1000	253	466	506,000	933,000		
1-in-1000	131	370	1,312,000	3,704,000		
UK ($2002)					42,146	43,677
5-in-1000	422	802	844,000	1,604,000		
1-in-1000	96	360	960,000	3,600,000		
France ($2002)					34,872	35,061
5-in-1000	522	---	1,043,573	---		
1-in-1000	---	---	---	---		
Italy ($2002)					27,233	43,698
5-in-1000	788	1,577	1,576,000	3,154,000		
1-in-1000	336	760	3,360,000	7,600,000		
Europe ($2002)					NA	NA
5-in-1000	573	1,230	1,146,000	2,460,000		
1-in-1000	---	---	---	---		
Japan[(a)] ($1999)					51,855	63,000
5-in-1000	113	323	193,000	551,000		
1-in-1000	50	148	427,000	1,262,000		
Chile ($1999)					NA	NA
5-in-1000	1,551[(b)]	---	310,277	---		
1-in-1000	413[(b)]	---	413,703	---		
China ($1999)					NA	NA
2-in-10000	---	22	---	110,000		
27-in-100000	---	54	---	200,000		

Notes: Adapted from Alberini *et al.* (2004a,b); (a) Krupnick *et al.* (1999); (b) Present value of monthly payments;

As can be seen in Table 7, the estimates of the value of a statistical life vary substantially between North American and European countries – the very small sample sizes in Japan, Chile and China suggest that these estimates are not representative and cannot be compared. For example, the value of a statistical life based on median willingness-to-pay values range between US$506,000 in Canada and US$1,576,000 in Italy, which can be regarded as unexpected given that the median income in the Italian sample was approximately half that observed in the Canadian sample. The same happens when estimates using mean willingness-to-pay values or the smaller risk reduction are used. If the Italian results, which seem not to be in line with the results obtained in other developed countries, are not considered, the figures seem to suggest that the value of a statistical life in developed countries – as estimated by the Krupnick *et al.* methodology for a 5-in-1000 risk reduction – ranges approximately between US$1.0 and US$2,5 million.

4.3. Averting behaviour studies

Some authors derived values of a statistical life from observations of the consumption of risk-mitigating goods. For example, Blomquist (1979) analysed how individuals value small changes in their probability of survival, through the analysis of automobile seatbelt use. Dardis (1980) investigated voluntary purchases of smoke detectors to estimate consumers' willingness to pay for risk reduction, while Jenkins *et al.*, (2001) analysed the purchase of helmets by bicycle users. Averting behaviour studies are not found easily in the literature when compared with compensating-wage and contingent valuation studies, possibly because of their characteristics and limitations that tend to be reflected in lower values of a statistical life. These limitations refer mainly to the discreteness of consumption ('yes/no' decision), and averting goods likely to generate joint benefits. However, the averting behaviour method is a revealed preference method that uses the willingness-to-pay approach, enabling analysts to derive willingness-to-pay estimates and the value of a statistical life for specific groups, that is, those consumers of the good being analysed. Some studies are reviewed below.

Blomquist (1979) developed a model of individual life-saving activity to show how the value of life saving is implied by observable behaviour, and estimated a value of a statistical life, based on the premium individuals pay in seatbelt use in order to reduce their risk of death. The framework presented, a two-period life cycle model with partly endogenous risk of death, explained the demand for life-saving activity and implied a necessary relation among the productivity and costs of the life-saving activity, and the value of a statistical life. The theoretical model will not be detailed here; instead, emphasis will be given on the empirical estimation of the value of a statistical life, which is demonstrated to correspond to the value of a unit change in the probability of survival and equal to the monetary worth to the individual of his or her future utility of consumption.

Empirically, in the case of seatbelt users, the value of a statistical life should be considered as money costs plus disutility costs less morbidity benefits, all divided by the change in the probability of survival. Seatbelt-use money costs would include time costs, such as installation of seatbelts and buckling, and disutility costs would consist of discomfort of using belts, distastefulness of buckling and unbuckling, and resistance to use due to habit. The author assumed disutility costs equal to zero given the difficulty in observing such data and, therefore, estimated lower-bound values of a statistical life. The data set used to estimate the value of a statistical life was the Panel Study of Income Dynamics, 1968-1974[39], which provided detailed information on seatbelt user characteristics. It is a nationwide (US) survey of 5,517 households followed throughout seven years, with approximately 500 variables for each household. The seatbelt use variable was equal to 1 if the driver claimed to use seatbelts all times and 0 if he or she claimed to use them none of the time. Passenger use and part-time use of seatbelts were not considered. Also, the sample was constrained to drivers whose cars had seatbelts installed in them to avoid the problem associated with the costs of purchasing a car with seatbelts or with having seatbelts installed. Another sample characteristic consisted in limiting the survey to drivers who were working in 1972 in order to avoid the problem of estimating the drivers' shadow wage rates.

Blomquist (1979) used probit analysis to determine the seatbelt productivity variables (those that determine the use of seatbelts) and concluded that (i) the age of driver, (ii) male gender and (iii) rural speed limit were the most important. The explanations were that (i) older drivers are more likely to be involved in an injury accident; (ii) women tend to drive under safer conditions than men; and (iii) high-speed driving is relatively dangerous. Other (cost) variables found to be important were the driver's wage rate (high-wage users face higher time costs); length of work-commutation trip and length of vacation (because longer trips relates to less fastening and unfastening); married driver and number of children; and education.

The time cost of seatbelt use was determined from estimates of the time required and the wage rate of the driver. The average time per one-way trip spent to use seatbelts was estimated to equal 8 seconds – the sum of 5 seconds for finding and fastening, 1 second for adjustment, and 2 seconds for unfastening. This average time, multiplied by the number of one-way trips per year produces the average annual time expenditure on

[39] Survey Research Center, 1972, 1973, 1974.

seatbelt use. The Probit coefficient of the wage-rate variable was then used to determine the standard deviation of net benefits (average annual time expenditure times the value of time in a vehicle relevant to the valuation of benefits of time-saving projects divided by wage-rate coefficient equals to US$16.79). The author weighted results from different studies to assume the effectiveness of seatbelt use with respect to fatalities equal to 0.50, while effectiveness with respect to non-fatal injuries was assumed equal to 0.25. Thus, based on accident and driver data, the estimate of the probability of death in a car accident was 3.027×10^{-4}, and while using seatbelts it was 1.514×10^{-4}. The average non-fatal injury loss that can be avoided by seatbelts was obtained in the traffic safety literature and assumed to equal US$950[40]. With these estimates and assuming that all drivers would use seatbelts if all costs, disutility and time were zero, the value of a statistical life was estimated to equal US$368,000 in 1978 dollars. This value depends on the point estimate of several terms as well as the value chosen for the value of the probit equation when all individuals use seatbelts, which determines disutility costs, according to the Blomquist (1979) model. The author provided a sensitivity analysis of each of these parameters, generating values ranging between US$229,000 and US$820,000.

The Blomquist (1979) study was original when using seatbelts as a life-saving good. It benefited from the fact that only 23% of US drivers used seatbelts at the beginning of the seventies, which enabled the use of probit analysis to estimate the value of life for the typical driver who did not use seatbelts. As the author stated, the value of life was inputted using the theory about seatbelt-use time costs, information on these costs, and the coefficient of wage rate to convert standardised into actual costs. Such a study would not be possible nowadays, since the use of seatbelts is mandatory in most countries.

Dardis (1980) used smoke detectors as the life saving good of analysis to estimate consumer's willingness to pay for risk reduction and, consequently, the value of a statistical life. It was assumed that smoke detectors have to be replaced after ten years and that the average household with smoke detectors owned 1.5 of them. Cost of using smoke detectors included purchase (market) price and annual replacement cost of batteries. Two discount rates were used to estimate annualised costs (5% and 10%),

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[40] It consists of labour productivity loss ($850) plus an admittedly arbitrary amount for pain and suffering ($100). Costs of property damage and insurance administration are excluded since these are costs that are not avoided by using seatbelts.

reflecting the consumers' subjective opportunity cost of saving or borrowing. The author used a range of weighting schemes to account for uncertainty concerning the relative importance attached by households to the probabilities of death or injury. The first scheme assigns that consumers consider that 50% of the value of using smoke detectors regards injury; while the last scheme means that the individual attaches no value (0%) to the reduction in the probability of injury and is only concerned with a reduction in the probability of death. The author claimed that the latter weighting scheme is considered to be the most realistic for smoke detectors since educational campaigns have focused on their life saving role.

The change in probabilities of death and injury was estimated based on the number of residential fire deaths and injuries, operating rates for smoke detectors and the degree of protection provided by smoke detectors. Dardis (1980) estimated that (i) 13% of households were equipped with smoke detectors in 1976; (ii) only 80% of installed smoke detectors were operational at one point in time; (iii) when combining household usage or saturation rate with operating rate yielded an effective saturation rate of 10% for all households; and (iv) smoke detectors only provide 45% protection against death and 30% protection against injury, based on a number of factors including inability to escape, inability to respond to an alarm, and failure to respond correctly. Combining these estimates with the number of residential-fire deaths in 1976 (approximately 6,200) resulted in 6,492 deaths in the absence of smoke detectors. Provision of smoke detectors in all households would have resulted in the avoidance of 2,337 deaths, corresponding to a probability of death reduction of 3.16 x 10^{-5} when combining death avoidance with the number of households in the US. This estimate was based on the assumption that residential fires involve one death only.

Dardis (1980) combined annualised costs of smoke detectors with weighted probability reductions to produce estimates of the value of life to purchasing households from 1974 to 1978. The resulting estimates were combined with sales of smoke detectors to yield the value of life to the total population. The annualised value of life for smoke detector users ranged between US$606,013 and US$676,266 in 1974 and US$137,342 and US$153,797 in 1979. The value of life for each period was multiplied by the relative importance of sales in each time period to produce the weighted value of a life to consumers – US$256,652 and US$294,968[41]. However, the author claims that

[41] Using weighting scheme 3 – mortality effect is the only concern of smoke detector uses. Different estimates are due to different discount rates used – 5% and 10%.

these estimates represent an overestimate of the value of life to the whole population at risk, since not all individuals bought smoke detectors. Upper bound values were inferred for non-users from 1979 data and assuming that the non-user population was informed of the risks from household fires. The values ranged between US$137,342 and US$153,797.

Jenkins *et al.*, (2001) studied the market for bicycle safety helmets to estimate the value of a statistical life for different age groups, including children. This is a major contribution of this study given the uncertainties involving child mortality valuation[42]. By using the same methodology and data to estimate values for both children and adults the authors provided a set of values for reduced mortality risks that are directly comparable across child and adult age categories. Another important feature of the Jenkins *et al.*, (2001) study is that bicycle helmets provide protection to a single member of a household, in contrast with smoke detectors (e.g. Dardis, 1980) that protect the entire household as well as material goods. Also, bicycle helmets do not generate any positive effect other than safety improvement, as can be expected to happen with other safety-related good, such as automobile size that proportionates additional comfort to car users (e.g. Atkinson and Halvorsen, 1990).

The assumption underlying the valuation exercise is that consumers (cyclists) purchase a helmet if their value for the reduced risk of head injury (whether resulting in death or not) is greater than the cost of the helmet, including the purchase, time and disutility costs. This means that the value of a statistical life is greater than the annualised cost of a helmet divided by the change in the probability of death due to the purchase and use of the helmet. In other words, this study generated lower bound estimates of the value of a statistical life for helmet purchasers[43] and, by implication, an upper bound estimate of the value of a statistical life for cyclists who do not purchase helmets.

The annualised cost of a bicycle safety helmet was estimated using average market prices, a replacement period of four years, and zero value for time (fastening/unfastening) and disutility (discomfort) costs for children and adults, given the difficult to obtain such data. The reduction in the probability of head-injury death was estimated as follows: an estimate was made of the number of bicycle trips by age

[42] There is growing concern about child mortality valuation issues, which is the subject of specific projects currently undertaken by US EPA and OECD. For example, how to treat parent's altruism since children do not take economic decisions.

group using results of a national survey; the number of deaths due to head injury from bicycle accidents; and the effectiveness of bicycle helmets at reducing mortality risk. This latter estimate combined the results of the survey (percentage of cyclists that wore helmets by age groups) and the percentage of reduction in severe brain damage from bicycle accidents by using helmets. The authors estimated that 79.83 head-related deaths occurred in 1997 among children aged 5 to 9 in the absence of helmets, and that 63.06 of those could have been avoided if helmets were used. Combining with the number of 5 to 9 years old children using bicycles produced a probability reduction of 4.41×10^{-6}.

The value of a statistical life for helmet users varied between US$1.3 and US$2.7 million (5 to 9 years); US$1.1 and US$2.6 million (10 to 14) years; and US$2.0 and US$4.0 million (20 to 59 years), according to different assumptions on the length of time using helmets and equal concern between death and injury. Table 8 summarises the value of a statistical life estimates generated in averting behaviour studies in the US.

Table 8: Summary of averting behaviour studies

Author (year)	Nature of the risk, year	Component of the monetary trade-off	Average income level (US$ 2000)	Implicit VSL (US$ millions 2000)
Blomquist (1979)	Automobile death risks, 1972	Estimated disutility of seatbelts	38,395	1.0
Dardis (1980)	Fire fatality risks without smoke detectors, 1974-1979	Purchase price and maintenance costs of smoke detectors	NA	0.77
Garbacz (1989)	Fire fatality risks without smoke detectors, 1968-1985	Purchase prices of smoke detectors	NA	2.56
Carlin and Sandy (1991)	Fatality risks with use of children's car seats, 1988	Purchase prices of car seats plus time to buckle children	24,737	0.84
Jenkins *et al.* (2001)	Bicycle-related fatal head injury risks, 1997	Purchase prices of bicycle helmets	NA	1.4 – 2.9 (5-9 years) 1.2 – 2.8 (10-14 years) 2.1 – 4.3 (20-59 years)

Source: Adapted from Viscusi and Aldy (2003)

As can be seen in Table 8, none of the averting behaviour studies refer to risk reduction in the context of air pollution. It can be argued that this is difficult to identify an averting good or service that clearly reduces the consumers' risk of dying from diseases associated with air pollution and, in addition, data regarding its consumption

[43] This is a theoretical limitation of the averting behaviour method that was discussed in Chapter 2.

and risk reduction can be easily obtained. For example, car catalyst can be regarded as a potential averting good related to air pollution but in most markets its use is already compulsory (consumers do not have choice about consuming or not), a characteristic that makes car catalysts not useful for an averting behaviour study. Another example can be the masks used by cyclists and pedestrians in most urban centres in Asia, but in this case the difficulty is to estimate the risk reduction associated with the use of these masks.

4.4. Other issues in valuation of risk changes

This section discusses some further practical issues involved in estimating willingness-to-pay measures for risk reduction and the value of a statistical life. It starts with a review of the issues related to the 'compensating-wage' method, once again mostly based on a recent study of Viscusi and Aldy (2003), and finishes with a discussion of other contingent valuation issues.

4.4.1. 'Compensating-wage' studies

The 'compensating-wage', or hedonic wage method, empirically estimates work-related values of a statistical life, using the wage-risk trade-offs (and other factors that affect wages) to estimate wage differentials related to different mortality risks. However, there are a number of difficulties associated with the estimation of the value of statistical life using this method. For example, Viscusi and Aldy (2003) detailed the econometrics and data issues in hedonic labour market analysis, such as: risk data measuring; omitted-variable bias and endogeneity; wages measuring and related data; the choice of a functional form for the hedonic equation; identifying inter-industry wage differentials; and the effect of union affiliation on the value of a statistical life. Black *et al.* (2003) used three different US data sets to estimate the price of risk[44] and matched these data to two sources of job risk data[45]. The main findings were that the estimates were quite unstable, and that this instability seems not to be due to specification error. Small changes in the specification of explanatory variables or the risk measured used resulted in large variations in the estimated price of risk. In addition, various estimates

[44] The Outgoing Rotation Groups of the Current Population Survey, the March Annual Demographic Supplement of the Current Population Survey, and the National Longitudinal Survey of Youth (1979)

[45] The Bureau of Labour Statistics estimates from their Survey of Working Conditions, and the National Institute of Occupational Safety and Health estimates from their National Traumatic Occupational Fatality survey.

indicated that the price of risk was negative, which is contrary to the theoretical framework used. These findings lead the authors to have doubts about the usefulness of existing value-of-a-statistical-life estimates to guide public policy. "These estimates are so highly sensitive to the risk measure used and the specification of the wage equation that the selection of any particular value of the price of risk seems arbitrary" (Black *et al.* 2003).

- Risk and wage data

Viscusi and Aldy (2003) argued that an ideal measure of job-related fatality and injury risk would reflect both the worker's and the firm's perception of the risk. Such data on perceived risks is generally not available and the standard approach is to use industry-specific or occupation-specific risk measures reflecting an average of observations of fatalities during a period of time. Measures of job-related fatality and injury in general includes self-reported risks based on worker surveys and objective risk measures derived from actuarial tables, workers' compensation records, and death certificates (Viscusi and Aldy, 2003).

According to Viscusi and Aldy (2003), the choice of the measure of fatality risk can significantly influence the magnitude of the risk premium estimated through regression analysis, a similar conclusion of Black *et al.* (2003). Viscusi and Aldy (2003) cited several early papers on compensating differentials that used the University of Michigan Survey of Working Conditions and Quality of Employment Survey data that included qualitative measures of job-related risk, which are generated using direct surveys of workers and their perceptions of their work environment. Other studies in the US used actuarial data and employed a job-related risk measure based on data collected by the Society of Actuaries for 1967. The majority of the studies of the US labour market used data collected by the US Department of Labour Bureau of Labour Statistics (BLS), which has maintained industry-specific fatality and injury risk data since the late 1960s. Finally, the National Institute of Occupational Safety and Health (NIOSH) has also collected information on fatal occupational injuries through its National Traumatic Occupational Fatalities surveillance system (NTOF) since 1980, using official death certificates.

Viscusi and Aldy (2003) concluded that most of the risk variables used in non-US studies were based on job-related accident and mortality data collected by official sources (government-reported); few of these studies indicated whether the mortality risk data were derived from samples or censuses of job-related deaths. For example, the data sets used in studies in India (Shanmugam, 1996; 1997; 2000; 2001) were from the Office of the Chief Inspector of Factories in Madras. Many studies in the UK employed data provided by the Office of Population Censuses and Surveys (Marin and Psacharopoulos, 1982; Arabsheibani and Marin, 2000), while others used unpublished data from the UK Health and Safety Executive (Siebert and Wei, 1994). In South Korea, accident data were obtained from the Ministry of Labour (Kim and Fishback, 1999). Additionally, the authors claim that while a large number of studies of labour markets around the world evaluated the compensating differential for a job-related death and injury, very few attempted to account for the risk of occupational disease such as cancer.

Finally, a common source of bias of 'compensating-wage' studies refers to using industry-based risk measures to reflect individuals' risk measure, which is likely to introduce a measurement error. According to Viscusi and Aldy (2003), applying industry averages to individuals may result in errors associated with matching workers to industry due to response error in worker surveys, or the possibility of some occupations within the industry facing risks that differ from their industry's average. As a result, this type of measurement error tends to have a downward effect on the risk coefficient.

Other necessary data in 'compensating-wage' studies are the wage data, characteristics of workers, and employment. Viscusi and Aldy (2003) observed that in some cases a survey asks workers directly to collect more reliable information (e.g. Lanoie *et al.*, 1995; Liu and Hammitt, 1999). In the US, the most used datasets are the Survey of Working Conditions (SWC); the Quality of Employment Survey (QES), the Current Population Survey (CPS) and the Panel Study of Income Dynamics (PSID). Black *et al.*, (2003) also mentions the Outgoing Rotation Groups of the Current Population Survey (ORG-CPS) and the National Longitudinal Survey of Youths (NLSY).

The dependent variable in a hedonic wage function in general is a measure of the hourly wage. However, Viscusi and Aldy (2003) argued that in some cases researchers have to construct the wage measure from weekly or annual labour earnings data. When the regression model includes workers' compensation benefits, then both the wage and the benefits should be expressed in comparable terms, in terms of tax deduction, to ensure proper evaluation of the impacts of the benefits on wages. According to Viscusi and Aldy (2003), researchers in general match a given year's survey data on wages and worker and employment characteristics with risk data for the same year or the average of earnings over a recent period.

- Specification of the hedonic wage function

A number of hedonic wage specification problems are well documented in the literature. These specification problems may include the functional form of the dependent variable; unobservable factors that may affect earnings; and the (non) inclusion of non-fatal risks. Regarding the functional form of the hedonic function, Viscusi and Aldy (2003) claim that this is an issue that cannot be determined on theoretical grounds. In general, two functional forms of the dependent variable are used, the linear and semi-logarithmic specifications (wage x log [wage] forms). Moore and Viscusi (1988a) employed a flexible functional form (the Box-Cox transformation) to identify the specification with greatest explanatory power. This approach presumes that a parameter exists such that when this parameter equals zero the model represents the semi-logarithmic functional form. When the parameter equals 1 then the model represents the linear functional form. Using maximum likelihood methods, Moore and Viscusi (1988a) estimated this parameter equal to 0.3 for their data, a result that is more consistent with a semi-logarithmic form than a linear form. Moore and Viscusi (1988a), however, rejected both specifications based on a likelihood ratio test and estimated similar values of a statistical life based on the Box-Cox transformed regression model and the semi-logarithm specification (Viscusi and Aldy, 2003).

Black *et al.* (2003) also tested a number of functional forms for the hedonic wage function as well as a non-parametric technique (propensity score matching) to produce estimates of the relationship between job risk and wages. In line with the conclusions of Viscusi and Aldy (2003), Black *et al.* (2003) concluded that the instability of the parametric estimates did not appear to be the result of the misspecification of the functional form of the regression function. The authors did not advocate in favour of any specific functional form, but used non-parametric estimates to conclude that the results continue instable.

Omitted variables bias is another source of specification problem raised by Viscusi and Aldy (2003). When possible determinants of a worker's wage are not specified in a hedonic wage equation this may introduce a bias, if the unobserved variables (confounders) are correlated with the observed variables. Viscusi and Aldy

(2003) argue that dangerous jobs are often unpleasant in other respects, such as environmental factors like noise, heat, or odour, which might be correlated with the risk measure. In fact, Black *et al.* (2003) investigated the possibility that unobservable factors were correlated with the risk measure and affecting earnings by using the NLSY data, which contains workers' characteristics not commonly available in labour economic data sets, such as illegal drug use and test scores for Armed Force qualifications. The authors found that job risk varies inversely with the Armed Force Qualification Test scores and varies positively with illegal (declared) drug use. In addition, individuals may systematically differ in unobserved characteristics, which affect their productivity and earnings in dangerous jobs, and so these unobservable factors will affect their choice of job risk[46]. Studies reviewed by Viscusi and Aldy (2003) indicate that models that fail to account for heterogeneity in unobserved productivity may bias estimates of the risk premium by about 50%.

In addition to unobserved factors, omitting injury risk can affect the estimation of mortality risk measures and represents another type of specification problem. Viscusi (1981) showed that a positive bias in the mortality risk coefficient is introduced when the wage equation omits injury risk. However, Day (1999) cited that a study by Martinello and Meng (1992) found that the inclusion of non-fatal risk measures in some specification models reduced the estimates of the value of a statistical life, while in other specifications the value of a statistical life increased. Viscusi and Aldy (2003) argued that the high correlation between injury and mortality risks is likely to introduce an econometric problem (colinearity) when analysts introduce both measures in the specification model.

Also, endogeneity is a common problem of 'compensating-wages' studies since the dependent variable (wage) is explained by, among others, the risk variable, which simultaneously depends on wage. Day (1999) claims that ignoring this issue may bias the estimates of the value of a statistical life downward since it is likely that those who are less risk averse, consequently requiring less compensation to accept risky positions, choose more dangerous jobs. In general, many of the estimates of the value of a statistical life accounting for endogeneity are two to three times as large as those estimated with risk as an exogenous variable (Day, 1999).

[46] Garen, J.E. (1988) "Compensating-wage Differentials and the Endogeneity of Job Riskiness", *Review of Economics and Statistics*, 73(4).

- Union effect

Regarding the effects of union affiliation on the value of a statistical life, Viscusi and Aldy (2003) argue that the relationship between union affiliation and the wage-risk trade-off has received substantial attention in the literature. Initially, it is believed that workers in union jobs receive greater premiums for facing risks than those workers in non-union jobs because if a worker lacks adequate information about the risks at the workplace, then this worker may underestimate the actual risks faced, and may demand lower wages than if this worker were aware of the risks. Unions potentially provide workers with more accurate information about their job-related risks and might also negotiate for mechanisms that increase worker exposure to safety information. However, the empirical tests cannot provide a conclusion about the union effect on wage-risk trade-offs. Most studies of the US labour market found that union affiliation is positively correlated with a greater wage-risk trade-off, while the international evidence is more mixed (Viscusi and Aldy, 2003).

Marin and Psacharopoulos (1982) conducted an analysis of compensating differentials for risk in the UK and found that union affiliation had an insignificant impact on the risk premium, the same result as in Arabsheibani and Marin (2000). In contrast, Siebert and Wei (1994) found higher union risk premiums, and Sandy and Elliott (1996) estimated larger compensating differentials for risk for non-union members. According to Viscusi and Aldy (2003), a follow-up study, Sandy *et al.* (2001), concluded that non-union workers enjoy greater risk premiums in the UK. In Canada, several analyses have found little support for a positive impact of union affiliation on compensating differentials for risk (e.g. Meng 1989; Martinello and Meng, 1992). In developing countries studies have also found mixed effects of union affiliation on a worker's risk premium. For example, Shanmugam (1996-7) included a union x fatality risk interaction term, and found that union members enjoy a positive compensating differential for risk in India. In South Korea, Kim and Fishback (1999) could not statistically identify compensating differentials for risk between union and non-union workers (Viscusi and Aldy, 2003).

4.4.2. Contingent valuation studies

Some issues are commonly discussed in the valuation of mortality environmental risk reduction literature as being important for the correct estimation of the benefits for the purpose of policymaking. It is argued that the economic theory is not conclusive about how these issues can be addressed. Those related to how the willingness-to-pay measure is dependent on respondents' age, and how future risks to human life can be valued in the present have been addressed in the theoretical literature review. In addition, there are ethical and moral issues involved in valuing statistical lives, and how altruistic individuals incorporate in their willingness to pay the concern with other individuals' lives. These important issues are discussed below.

- **Ethical and moral issues**

The value of a statistical life, defined as the aggregate willingness to pay for a measure saving a number of lives divided by the number of lives saved, is commonly referred to as the value of life and the value of preserving life. One of the most controversial aspects of valuing the benefits of reducing death risks is the pricing or placing of a monetary value on human life. For non-economists, this idea seems insensitive or inhuman. Perhaps, the idea becomes acceptable when individuals recognise that what is actually being valued is not life *per se*, but small changes in the probability of death.

Cropper and Freeman (1991) suggest that another way to characterise the economic approach when valuing changes in probabilities of death is by saying that the economic value is derived by focusing on choices *ex-ante*, before the uncertainty about whether or not the individual will die is resolved. However, this uncertainty about one's death is resolved at some point in time, which means that each individual at some point will know if he or she will die or will live a bit longer. From this *ex-post* perspective, the individual who will die would be willing to pay their total wealth to change the outcome or may require an infinite amount to compensate him or her to accept the death. According to some critics of the economic perspective, this difference in perspective can have no ethical or moral significance, meaning that neither willingness to pay nor compensation measures based on the *ex-ante* perspective are morally acceptable.

Cropper and Freeman (1991) argue that one defence of the economic perspective is based on the observation that people appear to be willing to make *ex-ante* trade-offs involving risks of death. Considering that individuals are rational and their preferences are the basis of economic value measures, then their willingness to consent to *ex-ante* trade-offs must have some ethical significance. In addition, for many of the public policy issues in which value of risk reduction information is used, it will never be known *ex-post* whose deaths were caused by failure to adopt a policy or whose lives were prolonged by a policy to reduce risks of death. The authors conclude with the argument that "...it is consent, and the veil of ignorance over who dies and who is saved, that legitimises the *ex-ante* perspective and its focus on the value of changes in risks rather than on the value of life versus death" (Cropper and Freeman, 1991).

- **Altruism**

Individuals may be concerned not only about their own welfare but also about other individuals' welfare. It is said that those individuals who are concerned about others' welfare express altruistic concerns, even when the good or service being evaluated does not personally affect them. These altruistic concerns are usually not observed on markets, making it difficult to estimate from market data (indirect methods) the total monetary value individuals place on mortality risk changes. It is said that benevolent altruism occurs when the individual cares about others' utility, and paternalistic altruism occurs when an individual cares about others' consumption. In general, it is assumed that individuals view people who are not in their family with benevolent altruism and view their families with paternalistic altruism.

In the context of risk reduction activities, the total benefit of a determined policy should be assessed by the society's total willingness to pay for the reduced risk. This willingness to pay would consist of two components: the private valuation consumers attach to their own risks change (pure self-interest), plus the altruistic valuation that other members of society place on their risks changes (Viscusi *et al.,* 1988).

Jones-Lee (1992) argues that under the willingness-to-pay approach, the value of a statistical life for a society of purely self-interested individuals is given by the population mean marginal rate of substitution of their own wealth for their own reduction in probabilities of death. In addition, if individuals are not purely self-interested but are also concerned for others' safety – and then willing to pay an amount for the reduction in probabilities of death – then the value of a statistical life should be augmented by an amount reflecting this additional willingness to pay. Furthermore, the author claims that it is appropriate to include the amount of individuals' willingness to pay for others' safety in the definition of the value of a statistical life if and only if altruism is exclusively safety-focused. That is because while an individual may be concerned and hence willing to pay for another individual's safety, the former individual is completely indifferent to the other determinants of the latter individual's wellbeing.

Finally, Jones-Lee (1992) concludes that the value of a statistical life for a 'caring' society would be 10% - 40% larger than the value that would be appropriate for a society of purely self-interested individuals. This conclusion is based on assumptions concerning the properties of the distribution of altruistic concern across the UK population (English households tend to the purely paternalistic form of altruism).

4.5. Alternative metrics for evaluating risk reductions associated with health

This section discusses the alternative metrics to the willingness-to-pay approach when used for valuing reductions in health risks, including fatal risks. Hammitt (2003) justifies the need of an alternative metric to the willingness to pay by arguing that individuals and societies make decisions that affect their exposure to a wide variety of health risks and some choices can have both beneficial and adverse effects for the same person. Making decisions about health risks, continues the author, is difficult and confusing; leading to situations where individuals can make choices that may conflict with their judgements. For example, individuals may be poor at understanding probabilities, especially the small ones that are relevant to health choices, and choose alternatives that in fact have greater health risks associated with them. For this reason, concludes the author, individuals may have difficulties in stating their willingness to pay for changes in their health risks.

This section briefly describes the concept of quality-adjusted life years (QALY), which evaluates interventions in terms of their cost-effectiveness—the cost per QALY gained. It is compared with the more usual willingness-to-pay metric, which is used in cost-benefit analysis to compare the value of health benefits with the cost of producing them. The relevance of this discussion is that the "US Office of Management and Budget, which oversees federal regulation, has recently proposed that regulatory agencies use both cost-effectiveness analysis (using QALY or other health measures) and cost-benefit analysis (using WTP) to evaluate rules intended to promote health and safety" (Hammitt, 2003). Both measures can be justified as measures of individual preferences over health risks.

Additionally, this section discusses the appropriateness of the value of a statistical life year (VSLY or VOLY), which is defined and compared with the value of a statistical life, when analysing mortality risks.

- **Quality-Adjusted Life Years (QALY)**

According to Krupnick (2004), the QALY measure uses the quality of a life year as the basic unit of account and aggregation, and is based on the product of the duration of a health state and a score (or weight) reflecting the quality of the health state[47]. Hammitt (2003) argues that QALY is used to measure an individual's future longevity and the quality of the individual's health during that time. In general, a score equal to zero represents death, and perfect health has a score equal to one. Thus, numeric values can be assigned to different health states so that morbidity effects can be combined with mortality effects to develop an aggregated measure of health outcomes. Another characteristic of the QALY approach is that life years are treated equally for all individuals, that is, the score attributed to perfect health, for example, carries the same value for all individuals regardless of any socio-economic characteristics such as age and income (Krupnick, 2004).

QALY measures are calculated by weighting the amount of time an individual will spend in each future health state by an index or score that measures the health-related quality of life in that state. If a person will live for (T) more years in a given state of health, the total QALY he or she will experience is equal to ($q \times T$), where (q) is the health-related quality of life associated with his or her health state ($0 \geq q \geq 1$). Health states perceived as worse than dead can be accommodated by using negative values of (q) (Hammitt, 2003).

Krupnick (2004) identifies several approaches for deriving scores or weights for the health index, including (i) rating scales (RS); (ii) time trade-off (TTO); (iii) person-trade-off (PTO); and (iv) standard gamble (SG). These approaches estimate the population's (or experts') average preferences for health states and derive weights for these states, bearing in mind that these approaches are not perfect substitutes. The rating scale, the simplest method for estimating weights or scores, involves giving individuals

[47] Other health indices found in the literature share this characteristic. For example, the Health Utilities Index (HUI), EuroQol or EQ-5D, the Functional Capacity Index, the disability-adjusted life years (DALYs) index, the Years of Healthy Life Scale. The variations in these indices have to do with the methods used to elicit the weights to be assigned to various health states and the specifications of the domains underlying the health states (Krupnick, 2004).

a description of a health state and asking them to rate it on a numeric scale. It is an example of a psychometric approach to determine preferences (Krupnick, 2004). It does not involve trade-offs or decisions under uncertainty.

In the time-trade-off approach respondents are asked to make trade-offs between outcomes that occur with certainty. For example, respondents are asked how many healthy years of life they would like to give up in order to forgo specific symptoms. Krupnick (2004) argues that it seems to be a consensus among analysts that both approaches – the rating scale and time trade-off – are better suited for the evaluation of chronic symptoms than acute ones.

The person trade-off approach asks respondents to choose between helping a number of individuals in a certain health state and a different number of individuals in another health state (Krupnick, 2004). The objective is to vary the number of individuals in one of the classes and elicit the number of individuals that makes the respondent indifferent between the two alternatives being offered, deriving a score from this point. It is appropriate for analyses at the social level, rather than the individual level. Finally, the standard gamble approach incorporates both trade-offs and uncertainty over health states. According to Krupnick (2004), it is based on expected utility theory because respondents are asked to make choices under uncertainty. In general, continues the author, respondents are asked the probability of death that would make them indifferent to experience the described condition.

Krupnick (2004) compared willingness-to-pay and quality-adjusted-life-year measures according to a list of attributes identified as desirable. The criteria for judging these measures included different types of validity[48], comprehensiveness, ease of application, costs of developing estimates, how well uncertainty is addressed, whether averting behaviour is captured, whether qualitative risk attributes are included, and whether these measures bias choices towards certain groups. The main conclusions are summarised in Table 9. Regarding the criterion validity criteria, the author concluded that tested against conditions for preferences to represent utility[49], the literature seems to

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[48] **Criterion validity** - the degree to which it measures the theoretical construct under investigation or the true measure. **Context validity** – how close does the construction of the measure mirror the context for public policymaking. **Convergent validity** – if the measurement in question compares with some other measurement by a different approach. **Construct validity** – if the estimate has properties that are consistent with the theory underlying the construction of the measure. **Content validity** - if the design and execution of the study yielding the estimate conform to the generally accepted best practice.

[49] Mutual utility independence; constant proportional trade-off of longevity for health; risk neutrality over life span; additive independence of utility for health states across time periods; and income independence (Krupnick, 2004).

indicate that QALY fails for a given individual, although there is evidence that once aggregated for many individuals, some of these violations of assumptions cancel out. Willingness-to-pay measures, on the other hand, are derived from a theory that is utility based. With respect to context validity, Krupnick (2004) concludes that the willingness-to-pay metric in general fits the policy context better than the QALY metric, but both pay little attention to estimating preferences for community health improvements. QALY does better than willingness-to-pay estimates according to the convergent validity criteria, because the weights are confined to the [0,1] interval for QALY and are not so constrained for willingness to pay.

Another criticism of QALY as a measure is formalised by Doctor *et al.* (2004): "QALYs are computed by adjusting each year of life by the quality of life in which it is spent. They are intuitively appealing, i.e. easy to explain to doctors and policy makers, and are tractable for decision modelling, which explains their popularity in practical research. A disadvantage of QALY model is that it represents individual preferences for health only under restrictive assumptions. Empirical tests of the QALY assumptions have generally yielded negative results. These findings undermine the credibility of economic evaluations based on QALYs and may call into question the validity of some clinical and health policy decision models" (Doctor *et al.* 2004).

Hammitt (2003) argues that because QALYs describe preferences only with respect to longevity and health, they do not answer the question of whether the health benefits of a policy justify its cost. In this sense, the trade-off between health and other goals should be set outside the QALY framework, often by comparing the cost per QALY gained by the policy under consideration with the cost effectiveness of other interventions. In addition, the author argues that the QALY and willingness-to-pay metrics offer sharply conflicting perspectives about the relative importance of reducing mortality risk to different people, and these differences can matter when comparing programs that disproportionately affect different sub-populations. For example, reducing the risk of automobile crashes, which most affects young adults, or reducing levels of air pollution, which most affects elderly people with chronic heart and lung disease. Under the QALY metrics, the value of reducing current mortality risk to a person is proportional to the person's life expectancy and to the health-related quality of life the individual will experience. In other words, the QALY measure implies that it is more important to reduce mortality risk to people having a higher life expectancy and to those who will be healthier. Under the willingness-to-pay metric, the relative value of reducing mortality risk is less sensitive to life expectancy and health prospects, but is sensitive to wealth and income.

Hammitt (2003) concludes that health metrics should ideally rank changes in health risk in the same order that individuals would rank them for themselves, and that society would rank them across individuals. If the individual and social rankings differ, it is theoretically possible that every individual would prefer the health risks he or she faces under policy A to those he or she faces under policy B, even though policy B scores better on the social ranking. There is some conflict between the goals of consistency with individual and with social preferences, and willingness to pay and QALYs differ in their emphasis on satisfying each of them. Empirically, neither QALYs nor willingness to pay is measured with great precision, and the differences in how the two metrics rank different policies may not be as sharp in practice as they are in theory. Evaluating policies from both perspectives may help to develop greater insight about the difficult health choices that societies must make (Hammitt, 2003).

Table 9: Comparisons of Health Valuation Measures for Technical Attributes

Attributes	Quality-Adjusted Life Year (QALY)	Willingness to Pay (WTP)
Criterion Validity		
Tested against conditions for preferences to represent utility	Key assumptions violated by individuals, but may perform better in the aggregate.	Performs well.
Comparison to actual choices	Standard gamble (SG) scores predict treatment choices	Concern over hypothetical bias for stated preference (SP) studies; difficult to make head-to-head comparisons of SP with actual choices
Context Validity	SG does fairly well in invoking trade-offs, but not in context of reduced health risks; person trade-off (PTO) reflects community-level choices; health domains/states defined on medical interventions may not match health outcomes relevant for policy interventions.	Performs well; however, most health valuation studies are for individual preferences rather than community preferences.
Convergent Validity	Differences in preference weights by approach; SG is the only utility-consistent approach and depends on cardinal utility assumption, but is insensitive to changes in health status.	Differences in revealed preference (RP) and stated preference (SP); SP has potential to better match choice context.
Construct Validity	Focus is more on testing validity of indices than validity of weights. Weights are sensitive to duration of effect, violating independence assumption. Difficult for people to make SG trade-offs. Duration estimates often unreliable or ad hoc. Yet, QALY indices can predict medical consumption.	Performs well, except proportionality to scope/scale for contingent valuation method (CVM).
Content Validity	Critics charge little attention given to "weights" surveys except in the construction of health state descriptions. Proponents say there is extensive work on this topic.	Major thrust of SP literature
Comprehensiveness	More comprehensive than WTP, but for health only. Combines mortality and morbidity.	Less comprehensive than QALYs, but covers more than health; doesn't combine mortality and morbidity.
Ease of Application	Easy	Easy
Cost	Cheap to apply, but getting weights is expensive (though only a one-time effort).	Cheap to apply, but getting unit values is more expensive per endpoint than QALYs. Presumption is that measures have to be estimated for each health effect–duration combination and by context, but research approaches are changing.
Address Uncertainty in Weights (QALYs)/Prices (WTP)	Relatively little attention here, only in sensitivity analysis. Uncertainty in duration of health states not addressed.	Yes
Recognizes Avoidance Behaviour	No	Yes
Inclusion of Qualitative Elements of Risk	Embedded in preferences to unknown degree.	Embedded in preferences to unknown degree; beginning to be an object of research.

Source: Krupnick (2004)

- **Value of a Statistical Life (VSL) x Value of a Statistical Life-Year (VSLY)**

A pertinent discussion in the context of mortality risks related to air pollution regards the use of the value of a statistical life for every case of mortality. The argument is that many people whose deaths are associated with air pollution may have had a short life expectancy even in the absence of air pollution (harvesting problem, discussed in the epidemiologic literature review – Chapter 2). In this case, it seems unreasonable to value a death of someone with a short period to live the same value as the death of someone with many years of remaining life expectancy. For example, according to IVM (2000), the ExternE project suggested that value of a statistical life estimates should be restricted to valuing fatal accidents, mortality impacts in climate change modelling and similar cases where the impact is sudden; and when the affected population is similar to the general population for which the value of a statistical life applies. The view of the ExternE project team was that the value of a statistical life should not be used in cases where the hazard has a significant latency period before impact, nor when the probability of survival after exposure is altered over a prolonged period, or where the life shortening is very limited. In such cases the years of life lost (YOLL) approach is recommended, and value of a statistical life year (VLYL, VSLY or VOLY)[50] estimates should be used.

The value of a statistical life is a risk-based unit of measurement while the value of a statistical life year is considered to be a life-span-based unit. VSLY should reflect the willingness to pay for an extended period of an individual's life expectancy in a given health state, this period of time in general being one year. The main difficulty in adopting the VSLY as the metric in a stated preference study is that the willingness-to-pay value may be expected to be contingent on the health state in which the respondent expects to be at the time when he or she benefits from the extension in life.

An alternative procedure to stated preference methods that directly elicits individuals' willingness-to-pay for an extended period of life is to derive the VSLY from value-of-a-statistical-life estimates, where the observed value of a statistical life is the discounted present value of future years, allowing for the survival probabilities. However, the main argument used against adopting this procedure is that there are other

[50] VLYL – value of a life year lost; VSLY – value of a statistical life year; and VOLY – value of a life year. These are commonly used terms to designate the same concept.

significant factors[51] that determine individuals' willingness to pay for mortality risk changes in addition to life span. As a result, the conversion of a pre-determined value of a statistical life into a time-stream of VSLY is arbitrary, since the value of a statistical life itself appears not to be the result of individual thought processes involving the discounting of such a time-stream (EC NewExt, 2003).

The value of a life statistical year has been suggested in some specific contexts on the basis that it explicitly allows for differences in length of lost life from different environmental impacts to be taken into account in environmental damage estimation. According to EC NewExt (2003), the context of air pollution may be expected to produce changes in life expectancy that are measured in terms of days or weeks rather than years. This study outlines the main issues that should be considered in selecting the appropriate metric in the context of air pollution. Investigations were carried out on: (i) theoretical issues, (ii) construction of the utility function, (iii) applied issues, (iv) measurement of the willingness to pay, (v) comprehension of the unit by user community, and (vi) complementarity with measurement of physical units of environmental damage. The study concluded that epidemiologic studies seem to suggest that the VSLY should be used in the context of air pollution since it is only possible to estimate total years of life lost from air pollution, and not the number of deaths.

EC NewExt (2003) argued that one justification for adopting the VSLY metric is that it more easily resonates with users of the QALY metric, since they are both based on the implicit assumption that there is a positive relationship between utility and life expectancy. However, the different theoretical foundations underlying QALY and VSLY make them not directly comparable. For example, QALY assumes that preferences over health and life expectancy depend only on health consequences, whilst VSLY allows for the possibility that preferences over health outcomes depend on individual characteristics such as wealth[52] as well as on the nature of the cause of impact (involuntariness).

In a context where the average age of the victim or the normal life expectancy within the relevant population are not known, the use of the value of a statistical life metric is recommended. However, in the context of air pollution, "the number of deaths

[51] For example, the emotional and personal costs to those who would be affected, which might be expected to peak in middle age when there are most likely to be young and/or old dependants.

[52] One argument used to justify the use of the non-monetary QALY measure is because it cannot be skewed by individuals' wealth or income; it may be seen as more equitable since everyone is assumed to have the same life expectancy.

that can be attributed to air pollution is only observable in mortality statistics when the effect is sufficiently instantaneous that the initial increase in death rate is not obscured by the subsequent depletion of the population who would otherwise die later" (EC NewExt, 2003). The authors argue that the usual case is that the impact of air pollution is not instantaneous but the cumulative result after years of exposure, so that the number of deaths is not observable. As a result, it is impossible to tell whether a given exposure has resulted in a small number of people losing a large amount of life expectancy or many people losing a small amount of life expectancy. In this case only the average number of years of life lost are calculable and this makes a case for the use of VSLY in the context of air pollution.

It seems that eliciting the VSLY directly by asking individuals how much they would be willing to pay for an extension in their life expectancy is, however, a difficult task. There are not many studies in the literature, which makes it difficult to evaluate precisely the caveats involved in a contingent valuation study designed for that purpose. Johannesson and Johansson (1997) undertook such an analysis in Sweden by asking respondents their willingness to pay for a programme increasing their life expectancy by one year, conditional on having survived until the age of 75 years. The authors also asked respondents to state their expected quality of life using a rating scale from zero (worst possible quality of life) to ten (best possible quality of life). It was shown to be a strong positive correlation of the expected quality of life at an advanced age and the willingness to pay for a one-year life extension, which suggests that the willingness to pay is highly sensitive to the size of health gain (scope). As a consequence of this strong link between quality of life in the future and the willingness to pay for a life extension in the future, the willingness to pay was very low – ranging between US$700 and US$1,300, since individuals expect a low quality of life at old ages. The authors concluded that to value a conditional increase in life expectancy is a difficult cognitive task.

4.6. Conclusions

An empirical literature review was undertaken in this chapter with focus on the main willingness-to-pay-based methods used to estimate the value of a statistical life. The review of the 'compensating-wage' studies, based on findings of recent meta-analysis studies (e.g. Viscusi and Aldy, 2003), presented values of a statistical life ranging between US$0.5 and US$20.8 million in US and US$0.2 (Taiwan) and 74.0 (UK) million elsewhere. The review of contingent valuation studies focused on those using the Krupnick *et al.* (1998, 1999) methodology. In this case the value of a statistical life did not vary as much as in the case of 'compensating-wage' studies. Instead, the estimates seem to range between US$0.5 million (Canada) and US$7.6 million (Italy). Averting behaviour studies, although not as frequent in the literature as other willingness to pay methods, also presented a wide range of estimates – US$0.77 and US$4.3 million. Also, some meta-analyses of studies estimating the value of a statistical life were undertaken in an attempt to provide best-practice estimates. The proposed value of a statistical life ranged between US$1.5 and US$5.6 million. It can be concluded that the value of a statistical life estimates can be very sensitive to the method, data, assumptions and statistical methods used in the valuation exercise.

5. Estimating the willingness to pay for mortality risk reduction in Sao Paulo, Brazil

The previous chapters introduced the air pollution problem in Brazil and its impact on human health. An extensive literature review indicated the theoretical background and the main issues related to policymaking in air quality matters. The main objective of this chapter is to estimate the willingness to pay for small mortality risk reductions in Sao Paulo, Brazil, which enables the estimation of the value of a statistical life. This latter estimate, along with the value of a statistical life year, and their dependence on specific individual characteristics, are the relevant statistics involved in policy assessment in the context of air pollution.

This chapter is organised as follows. First, a description of the survey assumptions and elicitation instrument is provided in section 5.1. A descriptive analysis of the samples is presented in section 5.2, while section 5.3 shows the investigation of the determinants of inconsistent willingness-to-pay responses. Section 5.4 investigates the determinants of protest responses regarding the hypothetical payment for risk reductions. Regarding the estimation of willingness-to-pay values for small risk reductions, the section follows the recent literature on the economic valuation with stated preference techniques (Bateman *et al.*, 2002), which suggests the following procedure, described in sections 5.5, 5.6 and 5.7, respectively:

(i) To estimate non-parametric willingness-to-pay values for different risk reductions;

(ii) To estimate parametric willingness-to-pay values for different risk reductions using the constant-only bid function approach;

(iii) To test the consistency of estimates with the economic theory using parametric models with covariates.

The value of a statistical life and value of a statistical life year estimates are presented in section 5.8 and the summary of results and conclusions are in section 5.9.

5.1. The survey

As described in the empirical literature review, Krupnick *et al.* (1998) first presented this computer-based survey instrument (questionnaire) which had been developed to fill some gaps in the contingent valuation literature concerning the elicitation of willingness to pay for reduction in risks of death. This survey instrument was adapted to the Brazilian context[53] [54] and used to elicit the willingness-to-pay measure related to reductions in risk of death in Brazil. First, a brief introduction regarding the computer-based survey informed the respondents that it was part of a strictly academic, non-commercial, research, followed by a statement of its general objectives. The structure of the survey instrument is as follows[55]:

(i) Details of the samples

The surveys – pilot and final – were conducted in Sao Paulo, Brazil, in October-November 2002 and March 2003, respectively. At the outset of the pilot survey a series of institutions that work with the elderly in Sao Paulo were contacted. As a result, four universities and a bank agreed for the survey to be conducted on their students/employees[56]. The bank's employees were highly skilled professionals such as software analysts or developers, A class individuals and relatively wealthy people in Brazil. The surveys in the universities involved mainly classes B and C, i.e. upper and lower middle classes.

Previous information about the social characteristics of the students and employees involved in the mentioned groups did not exist. During the initial phase of the survey there were no specific sample selection criteria apart from the age of the respondents being between 40 and 75 years, and that the respondents should be resident in Sao Paulo. All members of the computer skill classes for the Third age (in general, women in the 50s to 70s), and all available and co-operative IT employees were interviewed. Given an observed initial gender and age bias, the next procedure was to contract professional assistance for the sample selection of extra interviews. The objective was to obtain a socio-economic and demographic respondent profile as close as possible to that observed for the population of Sao Paulo – a similar distribution of the different age groups, gender and income.

[53] A especial acknowledgement here is devoted to Mrs Brigitte Desaigues, Laboratoire de Stratégie Industrielle – Université de Paris 6 Sorbonne, and Mr. Kene Bounmy, BETA - Université de Strasbourg, who developed and provided the survey software adapted for the Brazilian case.

[54] For example, the baseline risks per age and gender were estimated from official Brazilian life tables; the main causes of death presented to respondents were based on official statistics; questions relating to race were removed from the questionnaire for legal reasons and because there are no mortality statistics in Brazil disaggregated by race; and questions related to religious matters were not specific to any religion, given the multitude of religions and sects in Brazil.

[55] The description of the questionnaire is based on EC NewExt (2003) and Krupnick *et al.*, (1997).

[56] Thanks for the invaluable collaboration of Romenio das Neves Catharino (UNIBANCO); Prof. Antonio Jordao Neto (PUC-SP and Universidade Santo Amaro); Prof. Antonio Simoes Ferreira Filho e Profas. Mariuza Pelloso Lima e Sandra Maria Valeria Patriani (Fundacao Instituto Tecnologico de Osasco); Prof. Joao Carlos Schimitz and Maria Julia Nogueira Amaro (Universidade Anhembi Morumbi).

The professional contracted for the sample selection was responsible for renting the computer laboratories as well as for the sample selection, observing the desired percentages among the different social classes, gender and age groups. Two different labs were used, one in a very popular region in central Sao Paulo and another in a sophisticated region, in an attempt to capture members of the socio-economic class A. In addition, two rounds of interviews were contracted. The first one achieved 156 interviews during three days in November 2002 and another round was performed in one day in December, achieving an extra 34 interviews. The pilot sample totalled 309 interviews.

The statistics of the pilot survey are in Section 5.2, providing evidence that adjustments would be necessary for the final survey, especially involving the high percentage of 'yes' responses to all offered bids. After increasing the bid values, a second round of the survey (Final) was conducted in March 2003, using only the professional sample selection, an experienced professional firm that had its own recruiting database, consisting of the addresses, contact numbers and socio-economic profile of thousands of residents in Sao Paulo. The individuals filtered from this database were contacted by telephone and invited to attend an interview in a computer lab at an agreed date and time[57]. An average of 70 interviews were conducted per day and ten computers were used simultaneously from 9:00-19:00 daily. The criteria used in the sample selection involved residents in Sao Paulo, aged 40-75 (percentages per age intervals reflecting the city population profile), belonging to social classes A, B and C (percentages reflecting the population statistics), and not having participated in the pilot survey (November-December, 2002). A total of 287 individuals were interviewed for the final sample[58].

The reason for not including classes D and E was the high level of illiteracy that exists in these groups and the potential for misunderstanding the probability concept within the questionnaire. Thus, given the limited financial resources for the research, it was decided to concentrate the research effort on those classes more likely to be able to

[57] Initially, one can point out a possible bias referring to the fact that all respondents must have had a telephone to be invited for the interviews. But a quite usual procedure in Brazil involves those who cannot buy a telephone: they use someone else's numbers for an initial contact and then reply the call. In general, even in very poor communities some kind of public communal number is available.

[58] Initially, a total of 300 individuals were contacted to attend the lab and answer the questionnaire, but heavy rains and a strike in the public transport system in Sao Paulo contributed to a large number of absentees. Also, budget constraints and the collaboration of different institutions during the pilot survey contributed for the pilot sample size being larger than the final sample size.

respond cogently to the survey. According to the last Brazilian official Census (IBGE, 2000), the population living in Sao Paulo had the following characteristics:

Table 10: Statistics of the population of Sao Paulo – aged between 40 and 75 years

Social Group	%	Gender	%	Age group	%
A	7	Male	47.7	40-49	45.1
B	26	Female	52.3	50-59	29.3
C	36			60-69	19.2
D and E	31			70-75	6.4
				40-64	85.2
				65-75	14.8

Source: Fundacao Seade (www.seade.gov.br)

It is important to emphasize that both samples cannot be claimed as fully representative of the population of Sao Paulo (10 millions inhabitants). Both samples were obtained observing the same gender and age distribution as those observed in Table 10, which was an attempt to minimise the consequences of a non-representative sample and the small sample size. The targeted sample size was 300 due to budget constraint. The survey design implied the payment in cash of an incentive for the respondent to attend the computer labs and cover his or her travel expenses. The amount paid for each respondent equalled R$25,00 (approximately US$7.50), which corresponds to a total cost of US$1,420 for the pilot sample (190 times US$7.50) and US$2,152 (287 times US$7.50)[59].

(ii) <u>Targeting the 40-75 years old population</u>

This feature was judged appropriate given that the aim of the survey was to discuss reductions in mortality risks in the context of environmental policy, particularly air pollution. Arguably, it is likely that the risk of death from air pollution related diseases – cancer, cardiovascular and respiratory diseases – becomes significant only in middle age (e.g. Saldiva *et al.*, 1995).

(iii) <u>Presenting mortality risks in annual risk changes over ten-year intervals</u>

The use of ten-year intervals allowed representing risk and risking changes in terms of chances per 1000, which could be represented graphically, thereby facilitating the respondents' comprehension of risk concepts. Graphs were used to explain probabilities of death that contained 1000 squares, where white squares denoted chances of surviving, red squares represented chances of dying, and blue squares showed reductions in the risk of dying. This characteristic of the survey instrument was adopted following extensive tests in North America that concluded that the use of grids with more than 1000 squares (i.e. 10,000 or 100,000) results in reduced cognition and a tendency to ignore small risk changes as being significant (Alberini *et al.*, 2004b). Because annual risk changes associated with air pollution policy are smaller than 1-in-1000, the risk change was expressed as change over 10 years. Baseline risks and payment schedules were also put in 10-year terms. The use of this mechanism was important to help individuals differentiate a 5-in-1000 risk reduction from a 1-in-1000 risk reduction and, consequently, to reduce potential scope problems, i.e. the tendency of contingent valuation respondents to report the same willingness to pay for a bundle of goods as for a subset of the bundle.

(iv) Providing general baseline risk per age and gender

After obtaining the respondent's age and gender within the survey, the Brazilian life table was used to provide the risk of death of an average individual of the same age and gender. The purpose of this was to help respondents better appreciate the context of mortality risks and to show them the effect of age on baseline risks in ten-year increments. The respondents were presented a grid with red squares representing their 10-year average baseline risks. This procedure, along with other specific features within the study, was intended to ensure that hypothetical bias was reduced. Hypothetical bias refers to the fact that respondents provide hypothetical answers to hypothetical questions, which may not be the same answers they would give in a real situation.

(v) Examples of life-saving activities

Examples of risk reducing activities, such as visiting a doctor and taking medication, were provided along with a reminder that these activities involve some cost, although no specific cost was suggested in the survey. The purpose of these explanations was to illustrate that in everyday life respondents do pay small amounts of money to reduce their mortality risks. Also, the reason for not providing the actual cost estimates was to avoid the possibility of these costs anchoring later willingness-to-pay responses. Further information was presented on leading causes of death according to age and gender and common risk-mitigating activities, both medical and non-medical.

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[59] The targeted sample size followed similar surveys carried out in the UK, France and Italy, as can be seen in section 6.4. The North American surveys used samples three times larger, but no information is available regarding the costs of sampling in those studies.

(vi) Illustrating the concept of probabilities and test of comprehension

The survey instrument introduced the concept of probabilities to the respondent, and specifically the probability risks of death, testing for comprehension of the concept. The examples used included flipping coins and the throw of a dice. The comprehension test was performed by describing two hypothetical people identical in every way, apart form the fact that one had a 5-in-1000 chance of dying over the next 10 years while the other had a 10 in 1000 chance of dying over the next 10 years. The respondents were shown side-by-side grids of the risks for both people and asked to select which person had the largest chance of dying. In case of a wrong answer, an explanation was provided and another test was performed. Even if respondents could distinguish these risks, they might not feel that the difference in risk was significant. Therefore, the survey asked which of these two people they would rather be or if they were indifferent.

(vii) The mortality risk as context free and the risk reduction as a private good

Willingness to pay for different risk reductions was obtained in a general context, i.e. not specifically in the air pollution context. Past observations during focus groups in the US and Japan indicated that individuals tend to lose the dimension of the risk size when the risk is presented relating to air pollution. Also, the method of delivering risk reductions was treated as a private good rather than as a public good. That is, the risk reduction was presented as being covered by health insurance nor delivered by environmental programmes that reduce the risk of death for the entire population, but being applied only to the respondent. This feature is designed to make the respondent think about his or her own risks, thereby avoiding free-rider behaviour. The link with the air pollution context comes from the risk sizes evaluated: "we ask respondents to value annual risk reductions on the order of 10^{-4}. For instance, the Pope *et al.* (1995) study predicts that a 10 $\mu g/m^3$ change in PM_{10} results in an annual average change in risk of death of 2.4 in 10,000, while studies based on time series generally predict that the same change in pollution levels results in a 0.8 in 10,000 risk change" (Krupnick *et al.*, 2002).

(viii) Respondents' health status

Respondents were asked whether they had ever been diagnosed as suffering from various diseases, including cancer and chronic heart or lung diseases. The same questions were posed about respondents' relatives. Individuals were asked to respond to a series of questions in order to capture the severity of any physical and psychological health condition. One purpose of these questions was to encourage the respondents to think about their health before responding to the willingness-to-pay questions. From the answers, it was possible to construct physical health scores, for example, an energy/vitality and general health score, and a mental score. The latter measured symptoms of psychological distress[60]. In addition, the respondents were asked to rate their current health relative to others of their age and gender, and to rate their expected health in ten years relative to their health today. They were also asked to rate their expected health at age 70 relative to their expected health in 10 years.

(ix) The willingness-to-pay questions

The respondents were asked to consider two risk reductions occurring over the following ten years. The first risk reduction was of 5 in 1000 from the baseline risk, while the second was of 1 in 1000. The willingness-to-pay question was presented to the respondents for each baseline risk reduction, and another willingness-to-pay question was introduced regarding future risk reductions (asked only for individuals aged 60 or less). This last question is particularly important for valuing environmental improvements related to conventional air pollutants and carcinogens, given that the benefits related to the risk reduction involved occur in the future while the costs of implementing such improvements are incurred in the present. The respondents were reminded that there is a chance they may not live to the age 70, making a payment today useless. A screen to elicit the strength of respondents' conviction in their willingness-to-pay responses followed each question.

The willingness-to-pay question format used in the surveys was the closed-ended or dichotomous choice format, with a follow-up question. In the present study, this format therefore involved offering a value (bid value) to the respondents and asking if they would be willing to pay that amount of money to buy a product that would reduce their probability of death in the following ten years:

> *"Suppose that the Health Ministry had approved a new product that, when used over the next ten years, would reduce your chance of dying from a disease or illness. This product would reduce your total chance of dying over the next ten years from X to Y. If you were to take this product you*

[60] Short Form 36, or SF-36. Ware, J.E.Jr., Kosinski, M. and Keller, S. (1997). *SF-36 Physical and Mental Health Summary Scales: a user's guide manual.* Lincoln: RI Quality Metric. For details about the health

would have to pay the full amount of the cost out of your own pocket each year for the next ten years. For the product to have its full effect, you would need to use it every year for all ten years. In answering the next questions, please assume that the product has been demonstrated to be safe and effective in tests required by the Government. Keeping in mind that you would have less money to spend on other things, would you be willing to pay R$ X per year for the next ten years (totalling R$ 10X) to buy this product?"

Depending on the respondent's answer, another dichotomous choice question was posed with a greater bid value if the response to the initial question was affirmative or a lower bid value if the initial response was negative. Following these questions a final (open-ended) question asked what would be the maximum value the respondent would be willing to pay for the product.

The dichotomous choice elicitation method is intended to reduce the possibility of strategic bias, whilst follow-up questions are used to allow the researcher to improve the statistical efficiency of the willingness-to-pay estimates obtained. According to Haab and McConnell (2002), double-bounded models increase efficiency over single dichotomous choice models in three ways. First, answer sequences 'yes-no' and 'no-yes' yield clear bounds on willingness to pay. For the 'no-no' and 'yes-yes' pairs, there are also efficiency gains due to additional questions, even when they do not bound willingness to pay completely, since they further constrain the part of the distribution where the respondent's willingness to pay can lie. Finally, the number of responses is increased, so that a given function is fitted with more observations, although statistically the number of observations is not doubled, since there is correlation between responses from a single individual (Haab and McConnell, 2002).

(x) Debriefing questions

The debriefing questions were intended to elicit the respondent's perceptions regarding aspects of the survey, such as the payment instrument. Answers to these questions were used to explain variation in stated willingness to pay.

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status indices refer to Krupnick et al. (2002).

5.2. Descriptive analysis

5.2.1. The pilot survey

As described in section 5.1, the pilot survey was initially conducted among students of Universities of Third Age in Sao Paulo and employees of a bank. After initial statistics were produced, a professional service was contracted to help obtain a socio-economic and demographic respondent profile as similar as possible to that observed for the population of Sao Paulo. Table 11 shows how the questionnaires were obtained.

Table 11: Origin of the questionnaire – pilot sample

Universities of Third Age	Less than 65	65 and over	Total
ANH	11	12	23
FITO	19	9	28
PUC	22	12	34
SAN	8	11	19
Subtotals	60	44	104
Institutions			
Bank	10	0	10
Private Lab 1	59	14	73
Private Lab 2	90	27	117
Subtotals	159	41	200
Own Laptop	4	1	5
Total	223	86	309

Initially, a series of tests were performed on the data collected, assessing the risk comprehension and the willingness-to-pay values provided by the respondents. Two particularly important tests were those that identified individuals who had poor understanding of the probability concept (Flag4) or were not consistent when stating the willingness-to-pay responses (Flag0). The purpose was to investigate whether excluding those individuals from the sample would significantly modify the estimates. For comparison, different sub-samples were used during all analyses: a full sample (total sample) and two 'cleaned' sub-samples (using Flag0 and Flag4).

Flag 0 indicates respondents who reported inconsistent values in both risk reduction willingness-to-pay questions. It means, for example, that the individual reported a maximum willingness to pay (using the open question format) lower than the bid he or she had already accepted to pay, or stated a maximum willingness to pay greater than an amount he or she had refused before. This would indicate that the respondent was not considering the bid values offered or was not paying sufficient attention while responding to the questionnaire. Flag 4 refers to individuals who answered both probability tests in the questionnaire wrongly. The first test was performed after providing a series of explanations and examples of the concept of probability for all respondents. In case of a wrong answer, a second test was performed. If the respondent gave a wrong answer again, indicating a poor comprehension of the probability concept, then this respondent was given Flag 4 equal to 1. Table 12 indicates the percentage of the sample for selected debriefing questions.

Table 12: Debriefs in the sample – risk comprehension – pilot sample

Flag	Description	N	%
Flag0	Inconsistent WTP values for both risk reductions valued	52	16.8
Flag1	Wrong answer in the first probability test AND shows preference for having the higher risk of death	11	3.6
Flag2	Wrong answer in the first probability test AND initially shows preference for having the higher risk of death, but changed preference when asked to confirm	8	2.6
Flag3	Shows preference for having the higher risk of death	53	17.2
Flag4	Wrong answer in both probability tests	20	6.5
Flag5	Shows preference for having the higher risk of death and confirmed	14	4.5
Flag6	Respondent states that had not understood probability well	26	8.4

Table 13 introduces selected descriptive statistics of the sample. Although only class A, B and C were interviewed, which means rich, upper and lower middle class, respectively, the average income level is around R$ 2.500 a month (less than US$ 10,000 annual income). It has to be observed that the bank employees, highly skilled professionals and A-class individuals, given the high inequality levels observed in Brazil, certainly have lifted the income average considerably.

Table 13: Descriptive statistics of the respondents – pilot sample

Variable	Total sample	Without Flag0 = 1	Without Flag4 = 1
Observations (n)	309	257	289
% of male	44.3	44.8	43.9
Age – mean (stdev)	57.3 (10.3)	57.4 (10.3)	57.0 (10.3)
Household monthly income – mean (stdev)	R$ 2,415.05 (R$ 2,726.78)	R$ 2,660.51 (R$ 2,808.64)	R$ 2,430.80 (R$ 2,764.79)
Individual monthly income – mean (stdev)	R$ 1,902.70 (R$ 2,389.82)	R$ 2,076.51 (R$ 2,447.57)	R$ 1,921.45 (R$ 2,425.13)
Years of education	9.2 (4.5)	9.5 (4.6)	9.3 (4.5)
% with health insurance	66.3	71.2	66.8

US$ 1 = R$ 3.53 during the survey period (Oct-Nov/2002).

Table 14 gives the gender distribution by age groups. Comparing the gender distribution in the sample with the same figures for Sao Paulo, it can be observed that the survey sample contains slightly more women (55.7% for the total sample) than the census data for Sao Paulo (52.3%). The age group distributions in the survey sample diverted from the populations' statistics, although the age group (51 to 60) figure was very similar between the survey sample (30.1%) and the population (29.3%). The differences can be explained by the fact that only two thirds of the sample had some selection control, whilst the other third, which had no control at all, was strongly biased towards older women.

Table 14: Frequency by gender and age groups – pilot sample

		Age Groups					
		40 – 49	50 – 59	60 – 69	70 – 75	40 – 64	65 – 75
Total sample	Men	46	40	32	19	103	34
	Women	42	44	60	26	120	52
	Both	88	84	92	45	223	86
Without Flag0=1	Men	37	36	27	15	87	28
	Women	33	36	50	23	100	42
	Both	70	72	77	38	187	70
Without Flag4=1	Men	46	36	28	17	98	29
	Women	41	39	59	23	113	49
	Both	87	75	87	40	211	78

The scenario-acceptance figures, expressed in Table 15, are similar among the different types of samples - total and cleaned samples, suggesting that those respondents who answered incorrectly to the probability tests and those who stated inconsistent maximum willingness-to-pay values had on average the same perceptions of the survey scenario. The relatively high percentage of respondents that had doubts about the product's effectiveness may have influenced negatively the willingness-to-pay estimates, suggesting that these scenario-acceptance variables have to be tested in all parametric estimations of willingness to pay to verify their effects on the estimates.

Table 15: Scenario acceptance – pilot sample

Percentage of respondents who…	Total sample	Without Flag0 = 1	Without Flag4 = 1
Did not believe the stated risks applied to them	18.8	18.3	19.0
Had doubts about the product's effectiveness	37.5	36.2	37.7
Had doubts about the product's effectiveness and stated that doubts affected WTP	18.8	18.3	20.1
Thought product might have side effects	34.0	33.9	33.9
Thought about other benefits of the product	48.2	49.0	49.5
Said other benefits influenced WTP	12.9	14.0	12.5
Did not understand the payment scheme	8.4	7.4	8.7
Did not consider whether they could afford the payment	22.3	22.6	22.8

Regarding the objective and perceived risks, the figures in Table 16 indicate small differences among the different samples. Approximately 40% of the sample (aged 60 or less) thought that they would live up to 70 years, which indicates some optimism among the respondents.

Table 16: Objective and perceived risks – mean (standard deviation) in 1000 – pilot sample

Risk	Total sample	Without Flag0 = 1	Without Flag4 = 1
Baseline risk of dying over the next 10 years (objective measure, assigned based on age and gender)	242 (185)	242 (183)	237 (183)
Chance of surviving until age 70 (subjective measure, ranges from 0 to 100%)	40.3 (38.7)	41.9 (39.1)	39.9 (38.3)

Table 17: Health status of the respondents (%) – pilot sample

Description	Total sample	Without Flag0 = 1	Without Flag4 = 1
Any of coronary, angina, heart attack, or other heart disease	24.3	24.1	23.9
Any of emphysema, chronic bronchitis or asthma	13.6	12.8	14.5
High blood pressure	31.4	30.7	31.8
Any of the above (heart, lungs or high blood pressure occurrences)	48.2	47.9	48.8
Has been diagnosed with cancer	9.7	10.1	10.0
Has visited emergency room or has been hospitalised in the last 5 years for respiratory or heart problems	15.9	15.6	15.2
Judges his/her health to be very good or excellent relative to others of the same age	81.5	80.9	81.3

Table 17 shows the general health status of respondents, whilst Table 18 indicates the medical literature based standard form (SF36) indices. Both results suggest a relatively healthy – physically and mentally – set of individuals, also confident about their health status when compared to other people of the same age.

Table 18: Additional index scores from SF-36 – mean (standard deviation) – pilot sample

Index (1 to 100)	Total sample	Without Flag0 = 1	Without Flag4 = 1
Role-physical score – measures the extent of disability in everyday activities due to physical problems	81.4 (35.1)	84.8 (32.2)	81.1 (35.1)
Bodily pain score – measures the severity of bodily pain and resulting limitations in activities	83.9 (19.8)	84.7 (19.7)	83.5 (19.9)
General health score – measures respondent's perceived general health	70.2 (15.5)	70.6 (15.8)	70.1 (15.3)
Vitality score – measures energy level and fatigue	63.3 (16.1)	63.3 (15.6)	63.1 (15.9)
Social functioning score – measures the impact of either physical or emotional problems on the quantity and quality of social activities	76.3 (15.7)	77.1 (14.7)	76.0 (15.9)
Role-emotional score – measures the extent of disability in everyday activities due to emotional problems	81.6 (32.3)	82.7 (32.3)	80.6 (33.0)
Mental health score – measures respondent's perceived mental health (happiness and peace of mind)	67.8 (18.6)	68.6 (17.6)	67.4 (18.5)
Physical functioning score – measures the extent of disability in everyday activities due to general health problems	78.1 (25.7)	80.4 (23.6)	78.3 (25.7)

Table 19 illustrates the offered values (bids) used in all dichotomous format willingness-to-pay questions – immediate 5-in-1000 risk reduction, immediate 1-in-1000 risk reduction and future 5-in-1000 risk reduction.

Table 19: Bid structure (R$ 2002) – pilot sample

Group of Respondents	Initial payment Question	Follow-up question (If yes)	Follow-up question (If no)
1	60	120	30
2	120	400	60
3	400	600	120
4	600	800	400

US$ 1 = R$ 3.53 during the survey period (Oct-Nov/2002).

A reason for concern is the high percentage of 'yes' responses for all bid values, especially for the immediate 5-in-1000 risk reduction (Table 20). Two possibilities may be considered, the bid values offered were too low or individuals did not consider their income constraint when stating their preferences. The first hypothesis was adopted and the bid values were increased for the second and final round of the survey.

Table 21 shows the percentage of respondents who stated zero willingness to pay for a given risk reduction. The general increase in percentages has to be observed when comparing the initial risk reduction – immediate 5-in-1000 – with the second suggested risk reduction – immediate 1-in-1000 risk reduction.

Table 20: Percentage of 'yes' responses to the initial payment question – pilot sample

		Initial Bid (Brazilian Reais - R$)			
		60	120	400	600
5-in-1000 risk reduction over 10 years starting now	Total sample	85.1	88.5	76.0	75.6
	Without Flag0 = 1	84.4	87.9	73.0	70.3
	Without Flag4 = 1	84.9	87.8	76.1	76.0
1-in-1000 risk reduction over 10 years starting now	Total sample	79.7	74.4	64.9	52.4
	Without Flag0 = 1	79.7	74.2	62.9	43.8
	Without Flag4 = 1	80.8	73.0	65.2	53.3
5-in-1000 risk reduction over 10 years starting at age 70	Total sample	65.1	66.7	69.6	53.9
	Without Flag0 = 1	73.0	69.1	68.4	45.2
	Without Flag4 = 1	65.1	64.4	71.4	54.2

Table 21: Respondents who reported willingness to pay equal to zero (%) – pilot sample

5-in-1000 risk reduction over 10 starting now			1-in-1000 risk reduction over 10 starting now			5-in-1000 risk reduction over 10 starting at age 70		
Total sample	Without Flag0 =1	Without Flag4 =1	Total sample	Without Flag0 =1	Without Flag4 =1	Total sample	Without Flag0 =1	Without Flag4 =1
12.9	13.6	13.2	24.7	25.7	24.2	16.8	17.5	16.9

5.2.2. The final survey

The final survey, as described in section 5.1, was fully conducted by a professional firm specialising in market surveys, with substantial experience in Sao Paulo. This firm selected respondents from its database of residents in Sao Paulo according to previously given desired statistics of the sample. It adopted the same approach as before to separate the sample in total and cleaned sub-samples. Table 22 presents the results, which indicate an increase in all percentages regarding the pilot survey, especially those figures referring to flags 0 and 4. The observed lower average education level and income (Table 23 and Table 13) may possibly explain this increase in the number of inconsistent answers and mistakes regarding the probability tests.

Table 22: Debriefs in the sample – risk comprehension – final sample

Flag	Description	Occurrences N	% of the sample with Flag equal 1
Flag0	Inconsistent WTP values for both risk reductions valued	81	28.6
Flag1	Wrong answer in the first probability test AND shows preference for having the higher risk of death	15	5.3
Flag2	Wrong answer in the first probability test AND initially shows preference for having the higher risk of death, but changed preference when asked to confirm	10	3.5
Flag3	Shows preference for having the higher risk of death	72	25.4
Flag4	Wrong answer in both probability tests	32	11.3
Flag5	Shows preference for having the higher risk of death and confirmed	28	9.9
Flag6	Respondent states that had not understood probability well	38	13.4

Table 23: Descriptive statistics of the respondents – final sample

Variable	Total sample	Without Flag0 = 1	Without Flag4 = 1
Observations (n)	283	202	251
% of male	44.9	45.5	45.0
Age – mean (stdev)	56 (9.46)	56 (9.46)	55 (9.3)
Household monthly income – mean (stdev)	R$ 1,185 (R$ 1,590)	R$ 1,277 (R$ 1,710)	R$ 1,230 (R$ 1,664)
Individual monthly income – mean (stdev)	R$ 844 (R$ 1,140)	R$ 912 (R$ 1,273)	R$ 872 (R$ 1,197)
Years of education	7.6 (4.2)	7.9 (4.2)	7.8 (4.1)
% has health insurance	43.8	41.6	42.6

US$ 1 = R$ 3.40 during the survey period (March/2003).

Table 24 presents the occurrences of men and women by age group in the final sample. Comparing the figures for the total sample (not cleaned) with those presented in Table 10 for the population of Sao Paulo, it can be observed that 78.1% of the final survey sample is aged between 40-64 while the corresponding percentage for the whole population is 85.2%. Along with other figures, such as those regarding the sub-group aged between 40 and 49 years, this may suggest that the average age of respondents in the sample is higher than it would be expected if this has to present similar figures than the population of Sao Paulo.

Table 24: Frequency by gender and age groups – final sample

		Age Groups					
		40 – 49	50 – 59	60 – 69	70 – 75	40 – 64	65 – 75
Total sample	Men	37	40	40	10	101	26
	Women	46	46	48	16	120	36
	Both	83	86	88	26	221	62
	%	29.3	30.4	31.1	9.2	78.1	21.9
Population statistics		45.1	29.3	19.2	6.4	85.2	14.8
Without Flag0=1	Men	29	27	30	6	73	19
	Women	30	35	33	12	85	25
	Both	59	62	63	18	158	44
Without Flag4=1	Men	32	35	38	8	90	23
	Women	46	40	41	11	110	28
	Both	78	75	79	19	200	51

Table 25 shows the percentage of respondents who accepted specific features of the scenario presented. In general, the figures are similar to those observed in the pilot sample, and also there are no significant differences among the sub-samples. The percentages are very high, indicating that respondents might not find the scenario credible. However, the same sort of problem was observed in previous studies (e.g. Canada), suggesting that it can be a problem in the valuation of health in contingent valuation studies.

Table 25: Scenario acceptance – final sample

Percentage of respondents who…	Total sample	Without Flag0=1	Without Flag4=1	Canada
Did not believe the stated risks applied to them	22.3	23.8	20.7	19.7
Had doubts about the product's effectiveness	36.4	35.6	36.2	30.6
Had doubts about the product's effectiveness and stated that doubts affected WTP	12.7	11.9	12.3	19.7
Thought product might have side effects	36.4	35.6	35.1	25.0
Thought about other benefits of the product	48.4	46.5	50.2	48.7
Said other benefits influenced WTP	8.1	7.4	7.6	20
Did not understand the payment scheme	11.7	13.4	11.9	13
Did not consider whether they could afford the payment	24.7	27.3	25.5	26

The following tables show the objective and subjective measures of risk faced by individuals in the final sample, as well as the health profile of the sample.

Table 26: Objective and perceived risks – mean (standard deviation) in 1000 – final sample

Risk	Total sample	Without Flag0 = 1	Without Flag4 = 1
Baseline risk of dying over the next 10 years (objective measure, assigned based on age and gender)	219.9 (170.7)	220.5 (168.4)	213.3 (167.6)
Chance of surviving until age 70 (subjective measure, ranges from 0 to 100%)	40.0 (37.9)	40.7 (37.4)	40.9 (37.8)

Table 27: Health status of the respondents (%) – final sample

Description	Total sample	Without Flag0 = 1	Without Flag4 = 1
Any of coronary, angina, heart attack, or other heart disease	23.0	20.8	23.1
Any of emphysema, chronic bronchitis or asthma	16.2	15.8	16.7
High blood pressure	34.6	32.7	33.1
Any of the above (heart, lungs or high blood pressure occurrences)	50.9	49.0	50.6
Has been diagnosed with cancer	9.5	7.9	8.4
Has visited emergency room or has been hospitalised in the last 5 years for respiratory or heart problems	20.5	19.3	19.9
Judges his/her health to be very good or excellent relative to others of the same age	81.6	83.2	81.3

Table 28: Additional index scores from SF-36 – mean (standard deviation) – final sample

Index (1 to 100)	Total sample	Without Flag0 = 1	Without Flag4 = 1
Role-physical score – measures the extent of disability in everyday activities due to physical problems	77.0 (37.0)	80.4 (34.9)	79.5 (35.3)
Bodily pain score – measures the severity of bodily pain and resulting limitations in activities	82.3 (20.1)	83.5 (18.9)	83.5 (19.4)
General health score – measures respondent's perceived general health	67.5 (15.9)	68.2 (15.3)	68.2 (15.7)
Vitality score – measures energy level and fatigue	62.6 (15.8)	62.8 (15.5)	63.5 (15.5)
Social functioning score – measures the impact of either physical or emotional problems on the quantity and quality of social activities	74.7 (17.6)	76.0 (15.9)	75.6 (17.0)
Role-emotional score – measures the extent of disability in everyday activities due to emotional problems	76.3 (34.3)	78.5 (32.3)	78.1 (33.0)
Mental health score – measures respondent's perceived mental health (happiness and peace of mind)	65.8 (17.5)	66.0 (16.7)	67.4 (17.1)
Physical functioning score – measures the extent of disability in everyday activities due to general health problems	72.2 (27.4)	76.1 (25.4)	74.4 (26.2)

Table 29 shows the bid values offered in the willingness-to-pay questions in the dichotomous choice format, whilst Table 30 presents the percentage of 'yes' responses for each risk reduction evaluated. A high percentage of 'yes' responses even for the highest bid value can still can be observed, although they have fallen for the immediate 5-in-1000 risk reduction, suggesting that the bid values were still too low or that individuals did not consider their income constraint when stating their preferences. The latter alternative is now more plausible, given, for example, the income differentials between Brazil and the US. In the US study the bid values corresponded to US$70-150-

500-725, almost similar to those used in the final sample. However, official data reports: "real average income from main job, received monthly by individuals more than 10 years old, occupied during the reference week", for the metropolitan region of Sao Paulo in March 2003 equal to R$1,055 (US$310), or approximately R$12,665 (US$3,725) per year (www.sidra.ibge.gov.br/bda/tabela/), almost ten times lower than the US average[61].

Table 29: Bid structure (R$ 2003) – final sample

Group of Respondents	Initial payment Question	Follow-up question (If yes)	Follow-up question (If no)
1	240 (US$70)	600	120
2	600 (US$176)	1,800	240
3	1,800 (US$530)	2,700	600
4	2,700 (US$795)	3,600	1,800

US$ 1 = R$ 3.40 during the survey period (March/2003).

Table 30: Percentage of 'yes' responses to the initial payment question – final sample

		Initial Bid (Brazilian R$)			
		240	600	1,800	2,700
5-in-1000 risk reduction over 10 starting now	Total sample	77.8	68.2	67.1	59.7
	Without Flag0 = 1	75.9	64.6	59.6	50.0
	Without Flag4 = 1	78.1	67.2	65.6	63.1
1-in-1000 risk reduction over 10 starting now	Total sample	70.8	51.5	43.8	54.2
	Without Flag0 = 1	66.7	37.5	26.9	39.6
	Without Flag4 = 1	68.7	53.4	45.3	58.5
5-in-1000 risk reduction over 10 starting at age 70	Total sample	71.1	61.0	57.1	54.9
	Without Flag0 = 1	65.7	46.4	48.3	54.0
	Without Flag4 = 1	72.5	64.9	62.2	58.3

Table 31: Respondents who reported willingness to pay equal to zero (%)– final sample

5-in-1000 risk reduction over 10 years starting now			1-in-1000 risk reduction over 10 years starting now			5-in-1000 risk reduction over 10 years starting at age 70		
Total sample	Without Flag0 =1	Without Flag4 =1	Total sample	Without Flag0 =1	Without Flag4 =1	Total sample	Without Flag0 =1	Without Flag4 =1
25.5	32.1	23.9	32.9	42.6	30.7	17.7	21.3	16.3

A correlation analysis was performed among all variables available in an attempt to anticipate any autocorrelation problems in the econometric estimations due to the use

[61] At this point of the research the possibility of a potential 'yeah-saying' bias started to be considered. It did not occur to me the possibility of such bias during the pre-test and pilot phases; when some debriefing questions could have been introduced in order to confirm the existence of the bias and to help reducing it.

of two or more eventual regressors linearly correlated. No statistically significant results indicated such linear correlations, apart from those expected, for example, variable 'age' with variable 'risk10', which indicates the baseline risk presented to the respondent according to their gender and age.

5.3. Determinants of inconsistent willingness-to-pay responses

The samples obtained from the two surveys – pilot and final – have been treated in three different ways during the descriptive analysis: without 'cleaning', excluding respondents who failed in both probability tests (flag4=1), and eliminating respondents who reported inconsistent maximum willingness to pay to both immediate risk reductions (flag0=1). This section provides an attempt to identify the main determinants of both inconsistent willingness-to-pay responses and failure in responding correctly to the probability tests performed during the survey. The objective is to obtain some insights about possible (if any) common factors among those specific groups of respondents, and to facilitate the econometric analyses. For example, initially, it might be reasonable to consider education level as a potential determinant for the understanding of the concept of probability and for providing consistent answers. The common socio-economic variables were tested along with some attitudinal variables. The answers to the 5-in-1000 immediate risk reduction (the first question) were used for all tests. Table 32 shows the final results.

Table 32: Probit model – Inconsistent willingness-to-pay responses

Regressors	Coefficient	Standard errors	Marginal effects
Constant	1.36293	3.23075	---
Age	-0.02127	0.11139	-0.00690
Age square	0.00005	0.00099	0.00002
Gender	0.06078	0.18109	0.01972
Years of Education	-0.01471	0.02358	-0.00477
Income (individual)	-0.00011	0.00010	-0.00004
Has visited an emergency room during the past 5 years?	-0.76106 (*)	0.28992	-0.24691
Self assessed comprehension of the concept of probabilities	-0.17713 (**)	0.06929	-0.05747
If respondent smokes	0.33242 (**)	0.20110	0.10785
If considered payment every year	0.71765 (*)	0.24977	0.19422
Initial bid value	0.00016 (**)	0.00009	0.00005
Mental health score	0.01121 (**)	0.00531	0.00364
Physical function score	-0.01138/(*)	0.00331	-0.00369
Pseudo R2	0.1246		
N	283		
Log-likelihood	-148.32439		

Notes: Dependent variable is Flag0 = Inconsistent maximum willingness-to-pay responses for both immediate risk reductions.
(*) Significant at 1% - (**) significant at 10%.

Regarding the determinants of inconsistent maximum willingness to pay for immediate risk reductions (flag0), the respondents' age and education level were not, as expected, significant determinants. Instead, the respondents' self-assessed comprehension of the concept of probability was significant, and the negative sign indicates that the higher the understanding of probabilities, the lower the likelihood of an inconsistent willingness-to-pay response. Other statistically significant determinants were the physical function score, whether or not respondents smoke and the dummy variable that indicates whether the respondents have visited an emergency room during the last five years. All of these are difficult to interpret. The physical function score indicates how the respondents rate their physical health to perform the daily activities. The negative sign suggests that the more physically healthy the respondents were, the lower the probability of stating an inconsistent willingness to pay. The mental health score is a significant variable in explaining inconsistent willingness-to-pay responses, although the positive sign of the parameter is unexpected. It would be expected that the higher the mental health score the lower the probability of an inconsistent answer. The initial bid offered to the respondent was also an important determinant of inconsistent responses and the positive sign indicates that respondents facing higher bids gave more inconsistent answers. This result may suggest lack of attention in responding to the questionnaire.

Table 33: Probit model – Incorrect answers to the probability tests

Regressors	Coefficient	Standard errors	Marginal effects
Constant	-0.27662	4.45902	----
Age	0.00821	0.15472	0.0009
Age square	0.00035	0.00133	0.00004
Gender	-0.48795 (**)	0.25998	-0.05349
Years of Education	0.02784	0.03255	0.00305
Income (individual)	-0.00007	0.00016	-7.57e-06
If married	-0.59971(**)	0.25061	-0.07737
If cardiac disease diagnosed in family and/or respondent	0.58891(**)	0.28294	0.05807
Subjective health status in 10 years time	-0.24906(**)	0.12183	-0.02730
If considered baseline risk as its own	0.44486(**)	0.25980	0.04877
If considered health status when 70 years old	0.70907(**)	0.34348	0.08483
Mental health score	-0.02504(*)	0.00761	-0.00274
Physical function score	-0.01098(**)	0.00445	-0.00120
Pseudo R2	0.2488		
N	283		
Log-likelihood	-75.020734		

Notes: Dependent variable is Flag4 = Wrong answer to both probability tests.
(*) Significant at 1% - (**) significant at 10%.

The statistically significant determinants of wrong responses to both probability tests (flag4) were the respondents' gender, mental health score, physical function score and some attitudinal variables. Men had more difficulty understanding the concept of probability, a result that confirms initial observation during the application of the questionnaires. Both mental health and physical function scores had the same expected negative effect over wrong answers. The weaker the health score the higher the probability of mistakes, the marginal effect of the mental health score being greater than the physical function score. The influence of the attitudinal variables, as well as the marital status of the respondents, is difficult to interpret.

It can be concluded that both the physical function and mental health scores would be important determinants of inconsistent willingness-to-pay responses and incorrect answers to the probability tests. However, as concluded in section 5.2, the general statistics of the original sample were similar to those of the 'cleaned' samples, which excluded respondents who stated inconsistent willingness-to-pay responses (flag0=1), and those respondents who failed in the probability tests (flag4=0). It may suggest that the econometric results might not be substantially different between the samples. The econometric analyses consider the different sub-samples and compare the results of the two sub-samples with the complete (total) sample.

5.4. Determinants of protest responses

It was identified in Table 31 that a high percentage of respondents stated a zero willingness to pay for a given risk reduction. As described before, after the double bound dichotomous choice questions, another (open) question asked the respondents to state their maximum willingness to pay. In case of 'no-no' answers to the bids offered, it was asked if the respondents would be willing to pay anything at all for the good being valued. It was considered a protest response when the respondents stated that they were not willing to pay any amount for the good being valued and stated that they did not consider their finances when answering the willingness-to-pay questions (a 'protest' dummy was created). This section attempts to identify possible common factors that determine the protest responses. The sample without any exclusion (total sample) and the responses to the first willingness-to-pay question posed (5-in-1000 risk reduction) were used.

As can be seen in Table 34 the statistically significant factors affecting the decision of protest are gender and income. The positive sign of the coefficient for income suggests that those richer individuals in Sao Paulo tend to protest, possibly because these are the individuals who already have a considerable tax burden in Brazil. The same result was observed in other contingent valuation studies in Brazil[62]. Women tend to protest less than men in Sao Paulo, according to the negative sign of the variable gender. No other socio-economic variable was statistically significant in determining protest responses. As expected, the initial bid value offered to the respondents had no effect on the respondents' decision to avoid payment.

Table 34: Probit model – Protest responses

Regressors	Coefficient	Standard errors	Marginal effects
Constant	-8.97368	5.74768	----
Age	0.22422	0.19208	0.02072
Age square	-0.00183	0.00167	-0.00017
Gender	-0.45929(**)	0.28421	-0.04245
Years of Education	0.00569	0.03444	0.00052
Income (individual)	0.00027(**)	0.00011	0.00002
If respondent has private health insurance	-0.08123	0.26937	-0.00751
If married	-0.02197	0.29681	-0.00204
Has visited an emergency room during the past 5 years?	0.70486	0.66439	0.06514
Degree of faith in religion	-0.11353	0.17215	-0.01049
Initial bid value	0.00004	0.00013	4.12e-06
Pseudo R2	0.1220		
N	283		
Log-likelihood	-56.441676		

Notes: Dependent variable is a dummy Protest = refuse to pay anything and did not consider the budget when stating willingness-to-pay values.
(*) significant at 1%; (**) significant at 10%.

5.5. Non-parametric willingness-to-pay estimates

Contingent valuation models with discrete choice questions allow the use of non-parametric distribution-free estimators of willingness-to-pay measures. When the pattern of willingness-to-pay responses is well behaved (i.e. decreasing acceptance of bid values as these values increase) the estimates of willingness to pay are not sensitive to the choice of distribution for the unobserved random component of individuals' preferences, or to the functional form of the preference function. However, when the distribution or the functional form might have some effect on the estimates of willingness to pay, the Turnbull non-parametric distribution-free estimator (Turnbull,

[62] For example, Ortiz *et al.* (2003) "Investigating Selection Bias in Contingent Valuation Studies: the case of censoring protest responses for preservation of a rain forest area in Brazil" Paper presented at the I Congreso LatinoAmericano y del Caribe de Economistas Ambientales, Cartagena, Colombia, July 2003.

1976) can provide the basis for comparison of the parametric estimates of willingness to pay (Haab and McConnell, 2002).

Responses to discrete choice contingent valuation questions offer the researcher only limited information regarding each respondent's true willingness to pay. If the respondent says 'yes' then willingness to pay is greater or equal to the bid offered, whilst if the answer is 'no', willingness to pay is less than the bid. According to Haab and McConnell (2002), consider a random sample of (T) respondents, each offered one of (M) distinct prices (t_j, $j = 1, 2, \dots, M$) for a project. Let (WTP_i) be individual (i)'s true willingness to pay for the project. If the individual responds 'yes' to the question 'Are you willing to pay (t_j) for the project?', then ($WTP_i \geq t_j$), if 'no', ($WTP_i < t_j$). Since (WTP) is unobservable to the researcher, it can be taken as a random variable with a cumulative distribution function ($F_W(W)$), the probability that willingness to pay is less than (W). Thus, the probability of a randomly chosen respondent having willingness to pay less than (t_j) is:

$$\Pr(WTP_i < t_j) = F_W(t_j) = F_j\,. \tag{91}$$

That is, (F_j) represents the probability that the respondent will say 'no' to a price (t_j)[63]. Hence, the (M) offered prices divide the full sample (T) in a vector of (M) sub-samples ($\boldsymbol{T} = \{T_1, T_2, \dots, T_M\}$), where ($T_j$) is the number of respondents who faced the offered price (t_j) so that ($\sum_{j=1}^{M} T_j = T$). Similarly, the number of 'yes' (Y) and 'no' (N) responses can be indexed according to the offered price, that is, ($\boldsymbol{Y} = \{Y_j, j = 1, 2, \dots, M\}$) and ($\boldsymbol{N} = \{N_j, j = 1, 2, \dots, M\}$). When the offered prices are assigned randomly to the full sample, the (M) sub-samples can be treated as independent samples from the full population (T), each receiving a bid or price (t_j).

In order to derive an estimate of ($F_W(t_j)$), it is defined a response variable ($I_{ij} = 1$) if individual (i) responds 'yes' to the offered price (t_j), and ($I_{ij} = 0$) if individual (i) responds 'no'. The unknown probability of observing (I_{ij}) is:

$$\Pr(I_j | F_W(t_j), T_j) = F_W(t_j)^{1-I_{ij}} . (1 - F_W(t_j))^{I_{ij}} \tag{92}$$

For a given sample of (T_j) independent and identical individuals each offered the same price (t_j), the probability of observing the set of sample 'yes'/'no' response ($\boldsymbol{I}_j = \{I_{1j}, I_{2j}, \dots, I_{T_j j}\}$) is:

[63] Initially, it is assumed that this probability is equal for different individuals.

$$\Pr(I_j|F_W(t_j),T_j) = \prod_{i=1}^{T_j} F_W(t_j)^{1-I_{ij}}.(1-F_W(t_j))^{I_{ij}} = F_W(t_j)^{\sum_{i=1}^{T_j} 1-I_{ij}}.(1-F_W(t_j))^{\sum_{i=1}^{T_j} I_{ij}} \quad (93)$$

If the sample is chosen randomly and the prices are assigned randomly as well, then the individual responses to each price can be interpreted as the outcome of individual Bernoulli trials with probability of success equal to $(1\text{-}F_W(t_j))$. Since the individuals are randomly chosen and their responses are independent, the probability of observing a given number of 'yes' responses to offered price (t_j), (Y_j), from a sub-sample (T_j), is the probability of (Y_j) successes in (T_j) independent Bernoulli trials with probability of success $(1\text{-}F_W(t_j))$. Defining $(Y_j = \sum_{i=1}^{T_j} I_{ij})$ as the number of 'yes' responses to (t_j), and $(N_j = T_j - Y_j)$ as the number of 'no' responses, the probability of observing the exact sample of responses to (t_j) becomes:

$$\Pr(Y_j|F_W(t_j),T_j) = \left(\frac{T_j!}{Y_j!.(T_j - Y_j)!}\right).F_W(t_j)^{N_j}.(1-F_W(t_j))^{Y_j}, \quad (94)$$

where the term in brackets represents the number of combinations of 'yes' responses that can occur in a random sample of (T_j) individuals.

Haab and McConnell (2002) demonstrated that assuming $(F_W(t_j))$ as an unknown parameter, denoted (F_j), the probability of observing (Y_j) 'yes' responses from (T_j) independent respondents becomes a function of (F_j). The authors argued that the maximum likelihood estimator for (F_j) could be found from equation (94), which represents the likelihood of observing (Y_j) 'yes' responses from (T_j) respondents. Solving the first order conditions of the log-likelihood maximisation problem for (F_j) produced the maximum likelihood estimate of (F) $\left(F_j = \frac{N_j}{T_j}\right)$. Intuitively, the maximum likelihood estimate of the probability that a randomly chosen respondent will not be willing to pay (t_j) is equal to the sample proportion of individuals that respond 'no' to (t_j).

When the offered or bid price increases, it is expected that the distribution function monotonically converges to one for large samples, that is, as the offered prices increase, the proportion of 'no' responses to each bid should increase. Alternatively, as the bid prices increase the percentage of 'yes' responses should decrease. However, as shown in Table 20 and Table 30, because of random sampling it is not rare to observe non-monotonic empirical distribution functions for some of the offered prices, that is,

($F_j > F_{j+1}$). In such cases, Haab and McConnell (2002) suggest two options, relying on the asymptotic properties of a distribution-free estimator and accepting the small sample monotonicity problems, or imposing a monotonicity restriction on the distribution-free estimator. The second approach is known as the Turnbull distribution-free estimator (Turnbull, 1976).

If a monotonically increasing distribution function is to be guaranteed, a monotonicity restriction $(F_j \leq F_{j+1}, \forall j)$ must be imposed and the set of (F_j) must be estimated simultaneously, that is, the sub-samples can no longer be treated as independent. The log-likelihood function maximisation problem to estimate (F_j, $j = 1, 2, \ldots M$) subject to the monotonicity restriction is:

$$\max \sum_{j=1}^{M} \left[N_j.\ln(F_j) + Y_j.\ln(1 - F_j) \right] \text{ subject to } F_j \leq F_{j+1}, \forall j. \tag{95}$$

For convenience, this problem can be written in terms of the probability mass points ($f_1, f_2, \ldots, f_M, f_{M+1}$) rather than the distribution function ($F_1, F_2, \ldots F_M$), where ($f_j = F_j - F_{j-1}$) is the weight of the distribution falling between price (j) and the previous price. In this form, the vector of probabilities ($f = f_1, f_2, \ldots, f_M, f_{M+1}$) represents a discrete form of the density function. Rewriting the likelihood function in terms of the unknown density parameters rather than the distribution function parameters, the likelihood maximisation problem becomes:

$$\max \sum_{j=1}^{M} \left[N_j.\ln(\sum_{k=1}^{j} f_k) + Y_j.\ln(1 - \sum_{k=1}^{j} f_k) \right] \text{ subject to } f_j \leq 0, \forall j \tag{96}$$

The solution to the above likelihood maximisation problem involves recursively finding the set of first order conditions. Haab and McConnell (2002) showed that if the proportion of 'no' responses to each successive offered price monotonically decreases, then the distribution-free maximum likelihood estimate of the density point at price (j) is the observed proportion of 'no' responses to price (j) less the sum of the density function estimates for all previous prices $\left(f_j = \frac{N_j}{T_j} - \sum_{k=1}^{j-1} f_k = \frac{N_j}{T_j} - \frac{N_{j-1}}{T_{j-1}} \right)$. The intuitive interpretation of these maximum likelihood estimates is that the best estimate of the probability of a 'no' response to price (j) is the sample proportion of 'no' responses to that price. The maximum-likelihood estimates for the probability that the willingness to pay falls between two prices is therefore just the difference in the 'no' proportions between those prices, provided the response 'no' proportions are monotonically increasing.

In the case of non-monotonicity of empirical distribution function from (t_j) to (t_{j+1}), Haab and McConnell (2002) showed that the solution involves combining (j^{th}) and $(j+1^{th})$ sub-samples into one group and dropping the $(j+1^{th})$ price producing

$$\left(f_j^* = \frac{N_j^*}{Y_j^* + N_j^*} - \sum_{k=1}^{j-2} f_k^* \right),$$

where the (*) denotes the Turnbull estimates. Once the estimates of the distribution function are pooled to guarantee monotonicity, the Turnbull estimates of the cumulative distribution function can be interpreted as unrestricted maximum likelihood estimates of the empirical distribution function.

A lower bound Turnbull estimate for willingness to pay can be derived considering the expected value of the random variable (WTP), assumed to be distributed between zero and the upper bound on the range of (WTP), namely (U). The expected value can be written as

$$\left(E(WTP) = \int_0^U W.dF_W(W) \right).$$

Dividing the range of willingness to pay in $(M+1)$ sub-ranges $(0 - t_1,\ t_1 - t_2\ \ldots\ t_M - U)$, the expected willingness to pay can be written as

$$\left(E(WTP) = \sum_{j=0}^{M} \left[\int_{t_j}^{t_{j+1}} W.dF_W(W) \right] \right),$$

where $(t_0 = 0)$ and $(t_{M+1} = U)$. Because $(F_W(W))$ is an increasing function, it can be assumed that $\left(\int_{t_j}^{t_{j+1}} W.dF_W(W) \geq \int_{t_j}^{t_{j+1}} t_j.dF_W(W) \right)$. Assuming that $(F_W(0) = 0)$ and $(F_W(U) = 1)$, it can be written that $\left(E(WTP) \geq \sum_{j=0}^{M} t_j.\left[F_W(t_{j+1}) - F_W(t_j)\right] \right)$. Hence,

$$\left(E_{LB}(WTP) = \sum_{j=0}^{M} t_j.\left[F_W(t_{j+1}) - F_W(t_j)\right] \right) \quad \text{or} \quad \left(E_{LB}(WTP) = \sum_{j=0}^{M} t_j.f_{j+1} \right) \qquad (97)$$

This lower bound estimate of willingness to pay offers a conservative estimate of willingness to pay for all non-negative distributions of (WTP), regardless of the true underlying distribution. The estimate produced from (97) represents the minimum expected willingness to pay for all distributions of (WTP) defined from zero to infinity, since ($E_{LB}(WTP)$) will always bound expected willingness to pay from below as long as the true distribution is defined only over the non-negative range.

The Turnbull estimation technique was used to compute distribution-free and conservative estimates of mean willingness to pay to reduce risks of death in Sao Paulo, Brazil. This procedure involves using the responses to the initial (dichotomous choice) payment questions, ignoring the responses to the follow-up questions, to compute the relative frequencies of the given willingness-to-pay intervals[64]. Table 35 reports the produced estimates for the final survey.

Table 35: Non-parametric (lower-bound) Turnbull estimation of annual willingness to pay (US$ 2003)

	5-in-1000 risk reduction over 10 years starting now			1-in-1000 risk reduction over 10 years starting now		
	Total sample	Without Flag0 =1	Without Flag4 =1	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	522.09	464.74	524.93	277.36	203.24	288.43

Estimates are distribution-free and conservative.
US$ 1 = R$ 3.40 during the survey period (March/2003).

Table 35 shows that the lower bound mean willingness-to-pay estimates are lower when individuals who gave inconsistent answers are removed from the sample (Flag0). The observed decrease in mean willingness to pay was around 11% in the case of the 5-in-1000 immediate risk reduction, and approximately 26% for the 1-in-1000 immediate risk reduction. However, those estimates are higher when respondents that presented poor understanding of the concept of probability are removed (Flag4). Comparing the figures for different immediate risk reductions, it is observed that the lower bound mean willingness-to-pay estimates are consistently lower – approximately 50% - when the risk reduction being valued is lower (1-in-1000). This is an expected result, since the good being valued is a normal good. However, these results only represent the lower bound estimates of the true willingness to pay. It is interesting to observe the parametric results and perform the internal validity test to check the proportionality of willingness-to-pay estimates.

5.6. Parametric willingness-to-pay estimates

According to Bateman *et al.* (2002), the bid function explains the variation in willingness-to-pay response based on the change in the characteristics of non-market good, prices of market goods, income and other socio-economic characteristics of the respondents. The theoretical background relies on an indirect utility function ($v(.)$), that describes the maximum amount of utility a respondent can derive from his or her income, (y), given the prices of goods, (p), and the level of provision of the non-market good, (q). Thus individual utility function is assumed to be dependent on other demographic and economic factors, (s). A quantity (c) is defined as the maximum monetary payment that would ensure that the respondent's well being with the higher level of provision of the non-market good is equal to his or her well-being at the lower level of provision. In other words, (c) represents the compensating variation measure of a change in welfare, that is, the respondent's maximum willingness to pay to achieve the increase in provision of a non-market good. In a mathematical form:

$$v(y, p, s, q^0) = v(y - c, p, s, q^1) \tag{98}$$

The bid function can be written in a general form as:

$$c = c(q^0, q^1, y, p, s, e) = WTP \leq y\,, \tag{99}$$

where (e) is assumed to be the part of willingness to pay that is determined by the unobservable tastes of the respondent for the non-market good.

The simplest specification for the bid function is given by the constant-only bid function model, and is of great importance in deriving estimates of the mean and median willingness to pay of a survey sample. It is specified as:

$$c = a + e \text{ and } 0 \leq c \leq y\,, \tag{100}$$

where (a) represents the location parameter of the assumed probability distribution, or the measure of central tendency of willingness to pay and corresponds to the 'average' willingness to pay of respondents in the sample[65]. It is recommended that the constant-only bid function estimation be used when the objective is to estimate mean and median willingness-to-pay values. In such situations, it is not important to determine whether willingness to pay is systematically influenced by the respondents' characteristics. That is, it is desired that the (a) parameter be not represented as a function of covariates.

With this theoretical background in mind, the mean and median willingness-to-pay values were estimated for the interval data model, which can be generated from the referendum or dichotomous-choice with follow-up question format.

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[64] The non-parametric estimation using responses for the follow-up questions is presented in Annex 10.3.

[65] The majority of probability distributions assumed in contingent valuation studies are based on the parameters representing (i) central tendency (location parameter) and (ii) the spread of willingness to pay values (scale parameter) around the central tendency parameter.

The responses for willingness-to-pay and follow-up questions were combined to generate intervals in which the unobservable respondents' willingness to pay are to be found. This model offers the greatest increase in efficiency of willingness-to-pay estimates because it allows the analyst to identify smaller intervals where the unobserved true willingness to pay is. By combining the respondents' answers to both willingness-to-pay questions, more information on the distribution of willingness to pay is obtained and this information lowers the variance of the mean and median willingness-to-pay estimates (Haab and McConnell, 2002).

It was assumed that the respondents' true willingness to pay is bound by their (disposable) income. That is, to generate intervals for willingness to pay given the answers to the dichotomous questions, the bound interval [0, annual income/2][66] was assumed when the respondent answered 'no-no' and 'yes-yes', respectively. Bounding willingness to pay is consistent with economic theory and leads to more reliable and plausible willingness-to-pay estimates (Haab and McConnell, 2002, pp 106).

Different probability distributions were assumed for the random variable willingness to pay, with emphasis on the non-negative distributions, including the Weibull, exponential, lognormal and log-logistic distributions. Non-negative distributions do not admit negative values for willingness to pay, which is a desired characteristic in this study since respondents should state a non-negative amount for the reduction in his or her risk of death. In order to select the appropriate probability distribution, that is, the one that best fits the sample data, the Akaike information criteria (*AIC*) was used. Akaike (1974) proposed comparing each log-likelihood adjusted by the specific number of parameters being estimated in a particular model. That is:

$$AIC = -2(\log \text{likelihood}) + 2(c + p + 1)), \qquad (101)$$

where (c) is the number of model covariates (in the case of this study $c=0$ for all distributions), and (p) is the number of model-specific ancillary parameters. Although the best-fitting model is the one with the largest log likelihood, the preferred model is the one with the smallest information criteria value. Table 36 shows the relevant figures:

[66] This ad-hoc procedure assumes that half of individuals' annual income equals their disposable income. Income tax in Brazil is payable in two levels, 10% and 27.5%, according to earnings. Other cumulative

Table 36: Goodness of fit of different non-negative willingness to pay probability distributions – Akaike procedure

	Weibull	Exponential	Log-logistic
Ancillary parameters	1	0	1
5-in-1000 immediate risk reduction			
Log likelihood	-404.57076	-412.72118	-386.82943
Akaike criteria	813	827	778
1-in-1000 immediate risk reduction			
Log likelihood	-266.02575	-273.87937	-255.97043
Akaike criteria	536	550	516

Although the log-logistic probability distribution presented the best goodness-of-fit indicator according to the Akaike method, the Weibull distribution was assumed in this study for two reasons. First, and most important, the Weibull distribution is assumed in the majority of similar studies in the literature (e.g. Markandya *et al.*, 2003; Alberini *et al.*, 2004b), which facilitates the comparison among the estimates. Second, the log-logistic and Weibull models have similar goodness-of-fit indicators with the sample data, which supports the choice of the Weibull probability distribution.

The statistical willingness-to-pay model using the Weibull distribution is estimated using the method of maximum likelihood (Alberini *et al.*, 2004b). The log likelihood function of the responses is defined as:

$$\log L = \sum_i \log\left[F\left(WTP_i^U;\theta;\sigma\right) - F\left(WTP_i^L;\theta;\sigma\right)\right], \qquad (102)$$

where (WTP^L) and (WTP^U) are the lower and upper bounds of the interval around the respondent's true willingness-to-pay value and $(F(WTP;\ \theta;\ \sigma))$ is the cumulative density function of the Weibull distribution with shape parameter (θ) and scale parameter (σ), defined as:

$$F(z;\theta;\sigma) = 1 - \exp\left(-\left(\frac{z}{\sigma}\right)^{\theta}\right) \qquad (103)$$

Table 37 shows the parameters of the Weibull model for both risk reductions.

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taxes, such as the compulsory contribution to social security, plus the high cost of living in Sao Paulo (e.g. housing) seem to suggest that this is a conservative assumption.

Table 37: Weibull accelerated failure-time model

	Total sample		Flag0 = 0		Flag4 = 0	
Regressors	Coefficient	Robust standard errors	Coefficient	Robust standard errors	Coefficient	Robust standard errors
	5-in-1000 immediate risk reduction					
Constant	7.61154(*)	0.08311	7.67814(*)	0.10103	7.60078(*)	0.08997
Shape parameter	0.83644	0.03642	0.81270	0.04066	0.82200	0.03736
Log likelihood	-404.57076		-295.59862		-361.84367	
N	240		172		213	
	1-in-1000 immediate risk reduction					
Constant	7.52176(*)	0.08489	7.45842(*)	0.09790	7.53810(*)	0.09251
Shape parameter	0.81076	0.03391	0.80993	0.04049	0.79450	0.03451
Log likelihood	-420.68683		-317.18323		-373.77635	
N	245		185		215	

Notes: Flag0 = Inconsistent maximum willingness-to-pay responses for both immediate risk reductions.
Flag4 = Wrong answer to both probability tests.
(*) significant at 1%; (**) significant at 10%.

According to Bateman *et al.* (2002, pp 244), the mean and median values for the Weibull distribution can be estimated as:

$$mean = \exp(a).\Gamma(1+\sigma) \text{ and } median = \exp(a + \ln(-\ln(0.5)).\sigma), \qquad (104)$$

where (a) represents the location parameter of the Weibull probability distribution and ($\Gamma(n)=(n-1)!$) is the gamma function.

Table 38: Parametric estimation of mean and median annual willingness to pay (US\$ 2003) – Weibull distribution (95% CI)[67]

	5-in-1000 risk reduction over 10 years starting now			1-in-1000 risk reduction over 10 years starting now		
	Total sample	Without Flag0 =1	Without Flag4 =1	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	653.47 (528.06 – 817.37)	712.06 (549.72 – 936.17)	653.95 (519.25 – 833.58)	609.99 (490.33 – 766.80)	572.95 (444.85 – 749.06)	629.02 (495.97 – 807.12)
Median	383.59 (337.82 – 434.17)	404.79 (346.36 – 471.03)	376.58 (327.93 – 430.92)	345.82 (303.42 – 392.96)	324.45 (279.35 – 375.19)	348.28 (301.67 – 400.75)

US\$ 1 = R\$ 3.40 during the survey period (March/2003).

[67] Mean and median annual willingness to pay using gross income (no disposable income adjustment)

	5-in-1000 risk reduction over 10 years starting now			1-in-1000 risk reduction over 10 years starting now		
	Total sample	Without Flag0 =1	Without Flag4 =1	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	970.80	986.82	966.75	834.21	740.61	866.03
Median	572.61	570.16	567.46	483.38	422.34	499.39

The mean and median willingness-to-pay estimates shown in Table 38[68] are consistent with the following criteria. First, the mean values are all greater than the non-parametric mean values (Table 35), which are supposed to be lower-bound estimates of mean willingness to pay. Second, lower values for the smaller risk reductions are observed in all estimates. However, willingness-to-pay estimates for different risk reductions are not proportional to the reduction in risk, i.e. the willingness to pay for a 5-in-1000 risk reduction is not five times larger than the willingness to pay for a 1-in-1000 risk reduction.

Table 39: Internal scope test: are willingness-to-pay values proportional to the risk reduction?

	Ratio 5-in-1000 / 1-in-1000 risk reduction over 10 years starting now		
	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	1.0713	1.2428	1.0396
Median	1.1092	1.2476	1.0813

As can be seen in Table 39, neither mean willingness-to-pay estimates nor median values increase in proportion to the size of the risk reduction, although median willingness-to-pay estimates present a little more sensitivity to the size of risk reduction. Interestingly, the ratio is higher for both mean and median estimates when the sub-sample cleaned using Flag0 is chosen. This result would be also expected when the sub-sample cleaned using Flag4 was used. Although the ratios suggest that the estimates fail the internal scope test, this failure is common to other results in the literature. For example, the ratios observed in similar tests in the US and Canada were 1.9 and 3.2 (median values), and 1.3 and 1.6 (mean values), respectively (Alberini *et al.*, 2004b).

As mentioned in the empirical literature review of contingent valuation studies, Hammitt and Graham (1999) discussed some reasons why stated willingness to pay are not sensitive to variation in risk magnitude. One possible reason, they argued based on the review of several studies, is that respondents might not understand probabilities, or lack intuition for the changes in small probabilities of death risk. Another possibility involves the fact that respondents might not treat the given probabilities as given to them, suggesting that stated willingness to pay would not be proportional to the amount

[68] To generate confidence intervals of VSL estimates the recommended procedure should be to estimate a number of different mean and median WTP for different samples generated by using simulation techniques (e.g. Monte Carlo, bootstrap). This procedure would enable the estimation of standard errors and confidence intervals for the Weibull parameters and, consequently, WTP estimates. Alternatively, the 95% confidence interval of the estimated parameters in the Weibull constant-only regressions was used to estimate 95% confidence intervals for mean and median WTP and VSL.

of risk reduction given to respondents, but should be proportional to changes in perceived risk. Finally, it is possible that respondents might not value changes in risk levels in a manner that is consistent with expected utility theory.

5.7. Validity tests of parametric willingness-to-pay estimates

This section aims to test whether the respondents' willingness-to-pay values were influenced by socio-economic and behavioural factors, and if these factors are in accordance with the economic theory. Following Bateman *et al.* (2002), a fully parameterised model should be estimated to establish the degree of non-randomness observed in the sample data. The variables that influenced the stated willingness-to-pay values must be identified. Typically, such variables include income, age, education, details of respondent's attitudes towards the good or service being valued, and information on respondent's current knowledge of the good or service. These variables were included as covariates in the willingness-to-pay model. This model does not necessarily have to make the same distributional assumptions as those used to estimate mean and median willingness to pay. However, the Weibull distribution was assumed again for ease of comparison with results presented in the recent literature (e.g. Alberini *et al.*, 2001, 2004a).

Because the objective now is to establish the degree of randomness of willingness-to-pay responses, all available variables were tested regardless of whether they are considered to be endogenous or exogenous to the decision of stating the willingness-to-pay values[69]. This is possible because the parameters themselves are not of interest, but their significance is important to establish the explanatory power of the model. The resultant statistical model is:

$$\log WTP_i = x_i.\beta + \varepsilon, \qquad (105)$$

where (x) is a vector of individual characteristics and risk variables, (β) is a vector of parameters to be estimated and (ε) is the error term. Table 40 and Table 41 show the statistical significant covariates and, eventually, those insignificant ones but essential for the analysis like income, gender, age and education.

[69] Econometric theory states that parameter estimates are biased when endogenous variables are included in the willingness-to-pay model.

Table 40: Validity test - willingness-to-pay for a 5-in-1000 immediate risk reduction

Weibull model	Total sample		Flag 0 = 0		Flag 4 = 0	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	8.93490(*)	2.19569	12.8802(*)	3.33478	7.06822(*)	2.32752
Gender	0.19891(**)	0.10389	0.26377(**)	0.13043	0.22420(**)	0.11129
Age	-0.05234	0.69270	-0.18042	0.10374	0.01953	0.07462
Age square	0.00051	0.00061	0.00160(**)	0.00090	-0.00017	0.00066
Years of education	0.00869	0.01401	0.00690	0.01906	0.01024	0.01548
Income	0.00064(*)	0.00015	0.00054(*)	0.00016	0.00061(*)	0.00015
If smoker	-0.14350	0.11537	-0.24127	0.15753	-0.2128(**)	0.12300
Degree of faith in religion	-0.02660	0.06650	0.01248	0.08566	-0.09962	0.08006
Has health insurance	-0.27606(*)	0.10651	-0.36658(*)	0.13758	-0.28481(*)	0.11081
If respondent is married	0.02361	0.13008	-0.03586	0.16651	-0.00066	0.14184
Children	-0.03672	0.18126	-0.27138	0.27371	-0.09724	0.19957
Self-assessed comprehension of the concept of probabilities	0.05096	0.04369	0.05299	0.06675	0.08665(**)	0.04742
If respondent considered his/her finances when stating WTP	0.21739(**)	0.12536	0.21550	0.16707	0.14056	0.13384
Role limitation physical score	0.00365(**)	0.00188	0.00509(**)	0.00254	0.00583(*)	0.00204
Energy vitality score	-0.00688(**)	0.00308	-0.00398	0.00362	-0.0076(**)	0.00361
Subjective expected age of death	-0.0691(**)	0.02945	-0.0816(**)	0.03480	-0.04719	0.03238
Scale parameter	0.7437524		0.7490718		0.7504294	
N	240		172		213	
Log likelihood	-273.76743		-193.29854		-240.89826	

Notes: (*) significant at 1%; (**) significant at 10%.

The most important results in Table 40 relate to the significance level and positive sign of the individual income variable. As would be expected from economic theory, willingness to pay for a reduction in risk of death has a positive relation with the respondents' income, since reducing mortality risk is considered to be a normal good. The fact that income is the most statistically significant covariate – for all sub-samples – is also in line with the contingent valuation literature, which states that willingness to pay is the maximum amount of money that the individuals are willing to pay for the provision of the good being valued.

It can also be observed that, apart from income, the statistical significant covariates are not the same across the sub-samples. It was an expected feature given the discussion in section 5.3, which investigated the possible determinants of inconsistent willingness-to-pay responses and wrong answers to both probability tests, exactly the occurrences considered to censor the sub-samples. Among the statistically significant regressors are (i) the self-assessed comprehension of the concept of probabilities, which ranged between one and five in an increasing scale of comprehension, (ii) a dummy variable indicating whether respondents considered their finances when stating willingness-to-pay values, (iii) the energy vitality score, (iv) the role limitation physical score[70], and (v) whether the respondent has any health insurance.

Important socio-economic variables that would be expected to explain willingness-to-pay estimates but were not found to be significant include gender, age, education and marital status. According to a correlation analysis performed in this study, these covariates were not significantly linearly correlated with income, which suggests that the importance of income in explaining willingness to pay did not affect the (low) importance of the other socio-economic covariates in explaining the dependent variable. Surprisingly, perhaps, whether a respondent smoked or not was not significant in determining willingness-to-pay values, which would be expected to be significant since smokers already take greater mortality risks and since health risks associated with smoking, such as respiratory diseases and cancer, are well established and advertised[71]. Furthermore, the variable representing whether respondents have children, which might be interpreted to indicate that respondents may have more concern about their future health and capacity for providing support, was also not statistically significant.

Very similar results were obtained when the same analysis was performed for the 1-in-1000 risk reduction willingness-to-pay estimates (Table 41). The most important differences were that additional to income and other behavioural variables, respondents smoking or not, and the degree of religious faith were then statistically significant for some sub-samples. It is difficult to establish the reason why these behavioural attitudes are important in explaining willingness to pay for a smaller risk reduction while they are not significant to determine willingness to pay for a 5-in-1000 risk reduction. The negative sign of the coefficient relating to the degree of religious faith indicates that the more (subjective) religious the respondents are the less the willingness to pay. This might be expected on the basis that the greater the faith the

[70] Role physical limitation score "measures the extent of disability in everyday activities due to physical problems. Low score indicates problems with work or other daily activities resulting from physical health; high score indicates no problems with work or other daily activities as a result of physical health". Energy vitality health score is a "bipolar scale measuring energy level and fatigue; mid-range score indicates that the respondent does not report feeling tired or worn out; score=100 indicates that in addition, respondent feels full of pep and energy all of the time" (Alberini *et al.*, 2004b). Both scales range from zero to 100.
[71] This result is in line with Viscusi and Hersch (2001), which state that cigarette smokers assume more job risk than non-smokers.

more the respondents transfer responsibility to the entities they believe in to protect them.

Table 41: Validity test - willingness-to-pay for a 1-in-1000 immediate risk reduction

Weibull model	Total sample		flag 0 = 0		flag 4 = 0	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	10.2731(*)	2.47587	12.0843(*)	3.71081	8.81256(*)	2.88181
Gender	0.19715(**)	0.11656	0.26035	0.16336	0.31512(**)	0.12579
Age	-0.09329	0.07338	-0.16256	0.10754	-0.05701	0.08447
Age square	0.00075	0.00063	0.00141	0.00091	0.00048	0.00073
Years of education	0.00366	0.01727	0.02342	0.02556	0.01275	0.01888
Income	0.00059(*)	0.00018	0.00041(**)	0.00021	0.00057(*)	0.00019
If smoker	-0.2478(**)	0.12924	-0.4732(**)	0.17977	-0.34844(*)	0.13227
Degree of faith in religion	-0.1794(**)	0.07693	-0.1863(**)	0.10629	-0.2011(**)	0.09297
Has health insurance	-0.18347	0.12773	-0.12177	0.17869	-0.11376	0.13996
If respondent is married	0.03287	0.14478	0.05071	0.20140	0.03951	0.17250
Children	-0.03503	0.20502	-0.14032	0.31015	-0.07871	0.23896
Self-assessed comprehension of the concept of probabilities	0.04297	0.04815	0.10556	0.06817	0.11322(**)	0.05491
If respondent considered his/her finances when stating WTP	0.23274(**)	0.12711	0.14878	0.16813	0.13930	0.13740
Scale parameter	0.8630446		0.9168229		0.869929	
N	245		185		215	
Log likelihood	-319.76955		-236.92525		-281.3393	

Notes: (*) significant at 1%; (**) significant at 10%.

- Pooled data (pilot plus final samples)

In order to confirm the validity tests performed on the final sample, the same model was executed with the pooled data, that is, appending the pilot sample to the final sample[72]. This makes it possible to investigate whether the willingness-to-pay estimates are random or, instead, can be explained by some socio-economic and behavioural variables, regardless of the sample. That is, it is intended to test whether the observed statistically significant variables remain significant when a different sample is considered. Adding the pilot sample in the analysis includes extra 309 respondents. Table 42 shows the results for the 5-in-1000 immediate risk reduction while Table 43 presents the figures relating to the 1-in-1000 risk reduction.

[72] Thanks to Ana Alberini and other participants of the 14th Annual Congress of Environmental Economists for this suggestion. T-tests of equality of mean values between the pilot and the final samples are presented in Annex 10.2.

Table 42: Validity test - willingness-to-pay for a 5-in-1000 immediate risk reduction (Pooled data)

Weibull model	Total sample		Flag 0 = 0		flag 4 = 0	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	7.60572(*)	1.46501	8.15273(*)	1.71996	7.27616(*)	1.54770
Gender	0.04738	0.08703	0.11196	0.09601	0.03350	0.09103
Age	-0.02011	0.04815	-0.04022	0.05648	-0.00487	0.05116
Age square	0.00022	0.00042	0.00039	0.00049	0.00008	0.00045
Years of education	0.04674(*)	0.01078	0.04835(*)	0.01291	0.04827(*)	0.01153
Income	0.00045(*)	0.00005	0.00043(*)	0.00005	0.00044(*)	0.00005
If smoker	0.07816	0.10088	0.05872	0.11371	0.07056	0.10522
Degree of faith in religion	-0.07504	0.05235	-0.08014	0.06330	-0.1200(**)	0.06020
Has health insurance	-0.46210(*)	0.09442	-0.48831(*)	0.11755	-0.46035(*)	0.10101
If respondent is married	-0.02329	0.09154	0.00008	0.10121	0.00048	0.09711
Children	-0.16754	0.15821	-0.09648	0.19019	-0.19222	0.17313
Self-assessed comprehension of the concept of probabilities	0.06903(**)	0.03915	0.04164	0.04837	0.07062	0.04398
If respondent considered his/her finances when stating WTP	0.31939(*)	0.10294	0.38360(*)	0.12005	0.26411(**)	0.10595
Role limitation physical score	0.00133	0.00133	0.00050	0.00161	0.00185	0.00147
Energy vitality score	0.00032	0.00275	0.00175	0.00314	0.00007	0.00300
Subjective expected age of death	-0.01542	0.02613	-0.00675	0.03203	-0.00652	0.02926
Scale parameter	1.077121		1.088961		1.094792	
N	545		426		499	
Log likelihood	-926.86317		-773.14112		-856.33379	

Notes: (*) significant at 1%; (**) significant at 10%.

As can be seen in Table 42, almost the same set of variables that were significant in explaining the willingness to pay for a 5-in-1000 immediate risk reduction in the final sample (income, health insurance and if the responded considered his or her budget constraint) are important in determining the willingness to pay for this risk reduction using the pooled data. The main difference relates to the education variable, which is now statistically significant. The reason seems to be the higher education level observed in the pilot survey, one third of which consisted of students of Universities of the Third Age and highly qualified employees of a private bank.

Table 43 shows similar results for the 1-in-1000 risk reduction. In general terms, the same set of regressors was important in explaining differences in willingness-to-pay values using the pooled data, except that the education variable is now significant. The variable relating to smoking is now not significant, possibly because of the effect of the education variable.

Table 43: Validity test - willingness-to-pay for a 1-in-1000 immediate risk reduction (Pooled data)

Weibull model	Total sample		Flag 0 = 0		flag 4 = 0	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	9.86537(*)	1.84726	9.11027(*)	2.31734	9.44585	1.96584
Gender	0.06009	0.10804	0.15830	0.13195	0.09026	0.11562
Age	-0.0996(**)	0.05978	-0.08236	0.07336	-0.08473	0.06350
Age square	0.00086(**)	0.00052	0.00074	0.00063	0.00075	0.00055
Years of education	0.02291(**)	0.01335	0.03713(**)	0.01614	0.02094	0.01439
Income	0.00040(*)	0.00005	0.00037(*)	0.00005	0.00040(*)	0.00005
If smoker	0.05286	0.12800	0.02608	0.14335	0.02928	0.13539
Degree of faith in religion	-0.1391(**)	0.06872	-0.23788(*)	0.08253	-0.1552(**)	0.07960
Has health insurance	-0.41845(*)	0.11171	-0.3071(**)	0.14044	-0.40657(*)	0.12002
If respondent is married	0.04406	0.11945	0.05072	0.14465	0.05187	0.13029
Children	-0.04268	0.21058	-0.16414	0.24303	-0.08431	0.24012
Self-assessed comprehension of the concept of probabilities	0.09101(**)	0.04607	0.12872(**)	0.05847	0.10556(**)	0.05261
If respondent considered his/her finances when stating WTP	0.23209(**)	0.11747	0.15839	0.13860	0.16569	0.12293
Scale parameter	1.350752		1.416372		1.375685	
N	551		440		501	
Log likelihood	-1049.2796		-857.13581		-962.63673	

Notes: (*) significant at 1%; (**) significant at 10%.

From these results, it can be concluded that the willingness-to-pay estimates to reduce immediate probabilities of death in Sao Paulo seem to be robust, not sample-dependant, and not assigned randomly.

5.8. The value of a statistical life and the value of a statistical life year

The corresponding values of a statistical life were estimated using both median willingness-to-pay estimates (conservative estimates) and mean willingness-to-pay values. They were obtained by dividing the willingness-to-pay figures by the corresponding annual risk reduction being valued. It was assumed that respondents implicitly considered the risk reduction evenly over the ten-year period, which makes it possible to avoid discounting the respondents' annual payments. Table 44 shows the results.

As can be seen in Table 44, the values of a statistical life estimated from 1-in-1000 risk reductions are much higher than those estimated using the 5-in-1000 risk reduction, as expected since the willingness to pay is divided by a smaller risk variation. This is purely due to the lack of proportionality between the willingness-to-pay estimates regarding the differences in the size of risk reductions (Table 39). The estimates of the value of a statistical life reflect only differences in risk variation (almost five times bigger). In fact, these estimates of value of a statistical life, derived from willingness-to-pay estimates for different risk reductions, would be similar to each other if the mean and median willingness-to-pay estimates were proportional to the difference in risk variation. It is suggested that the value of a statistical life estimates derived from mean and median willingness-to-pay estimates for a 5-in-1000 risk reduction are of greater policy relevance since they represent more conservative estimates than those estimated using willingness to pay estimates for 1-in-1000 risk reduction[73]. Thus, for policy assessments in Sao Paulo conservative values of a statistical life ranging between US$ 0.77 – 1.31 million[74] are suggested.

Table 44: Value of a statistical life using parametric estimation of mean and median annual willingness to pay (US$ 2003) – Weibull distribution (95% CI)

	5-in-1000 risk reduction over 10 years starting now			1-in-1000 risk reduction over 10 years starting now		
VSL	Total sample	Without Flag0 =1	Without Flag4 =1	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	1,306,941 (1,056,127 – 1,634,736)	1,424,114 (1,099,432 – 1,872,330)	1,307,908 (1,038,495 – 1,667,161)	6,099,858 (4,903,276 – 7,668,017)	5,729,545 (4,448,499 – 7,490,598)	6,290,223 (4,959,711 – 8,071,165)
Median	767,187 (675,649 – 868,349)	809,587 (692,728 – 942,062)	753,159 (655,851 – 861,846)	3,458,245 (3,034,213 – 3,929,572)	3,244,472 (2,793,533 – 3,751,852)	3,482,806 (3,016,684 – 4,007,517)

US$ 1 = R$ 3.40 during the survey period (March/2003).

When compared with European and North American estimates these values seem to be higher than expected. Given the close link between willingness-to-pay estimates and the population income, lower willingness-to-pay values for developing countries might be expected. A possible reason for the high willingness-to-pay and value of a statistical life estimates found in the current study might have been the 'cooperative' behaviour observed in many of the respondents. A possible bias might have been introduced by the use of an incentive payment (R$25 or approximately US$7.5) to each respondent for his or her participation in the survey. Evidence for such a bias arose from a number of comments made by respondents to the effect that they were keen to take part in this survey and other such surveys, since the cash incentive

[73] In this survey, the 1-in-1000-risk reduction question is asked after the 5-in-1000-risk reduction question. Prior testing in the North American context indicated that answers to the second question tend to be less reliable than those to the first question. It is also likely to be an easier size of risk change to effectively comprehend.

[74] The results using cleaned sub-samples were not substantially different from the results using the total sample. Therefore, it is suggested the latter set of results for policy analysis in Brazil.

was important to them (minimum wage in Brazil was R$240 per month). It is possible that those respondents tried to be 'cooperative' or helpful by saying 'yes' to every question. This 'yeah-saying' behaviour has been observed in several contingent valuation studies using the dichotomous choice format for the willingness-to-pay questions (e.g. Ready *et al.*, 1986)[75]. It is believed that the relatively high figures in this valuation exercise may be partly due to this bias. This caveat can be regarded as a possible improvement for future contingent valuation studies in Brazil. On the other hand, as observed in Chesnut *et al.* (1997) for a study in Bangkok, in general health is seen as a basic necessity (like food or shelter) and those with lower incomes may be willing to pay a higher share of their income to protect their health (Chesnut *et al.*, 1997).

In order to test the hypothesis of 'yeah-saying' responses, the mean and median willingness to pay were estimated using a sub-sample where the 'yeah-say' respondents were excluded. A 'yeah-say' respondent was considered to be the individual who accepted all bid-values offered in both immediate (5 in 1000 and 1 in 1000) risk reductions. Table 45 shows the results, which, however, cannot be claimed as better results than those presented in Table 44 since it is not possible to distinguish genuine 'yes' responses (those obtained after an implicit utility maximising process constrained by income) from 'yeah-say' respondents. In other words, the procedure adopted here may have excluded some genuine 'yes' responses from the sample.

Table 45: Value of a statistical life using parametric estimation of mean and median annual willingness to pay (US$ 2003) – Weibull distribution (95% CI) – excluding possible 'yeah-say' responses

	5-in-1000 risk reduction over 10 years starting now			1-in-1000 risk reduction over 10 years starting now		
VSL	Total sample	Without Flag0 =1	Without Flag4 =1	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	489,752 (416,964 – 579,800)	497,935 (415,596 – 602,039)	468,760 (395,384 – 560,497)	2,412,626 (2,018,173 – 2,906,148)	2,436,371 (1,991,195 – 3,005,512)	2,319,842 (1,912,481 – 2,838,622)
Median	415,831 (369,841 – 465,793)	416,643 (364,958 – 473,670)	398,711 (351,760 – 450,101)	1,971,617 (1,728,805 – 2,241,120)	1,948,903 (1,675,951 – 2,258,600)	1,883,779 (1,633,927 – 2,163,724)

US$ 1 = R$ 3.40 during the survey period (March/2003).

The income-elasticity of willingness to pay was estimated by regressing a double-log model with income as the explanatory variable of willingness-to-pay

[75] In fact, this conclusion is based on qualitative analysis of respondents' comments after attending the survey. Quantitatively, however, the percentages of 'yeah-saying' respondents were similar

responses. The results suggest the income-elasticity of willingness to pay equal to 0.9087 (5-in-1000 risk reduction) and 0.8331 (1-in-1000 risk reduction). Table 46 shows the results for all sub-samples of interest. The results excluding 'yeah-saying' respondents were not statistically significant at the usual level, which undermines the validity of these figures.

Table 46: Income elasticity of willingness to pay – double-log model – Weibull distribution

Risk	Sample *including* 'yeah-saying' respondents		
Reduction	Total sample	Flag0	Flag4
5-in-1000	0.9087	0.9020	0.9276
1-in-1000	0.8331	0.7430	0.8760
	Sample *excluding* 'yeah-saying' respondents		
5-in-1000	0.0515	0.0470	0.0821
1-in-1000	0.0126	0.0047	0.0386

US$ 1 = R$ 3.40 during the survey period (March/2003).

- **The value of a life year lost (VLYL)**

This empirical study is devoted to estimate the willingness to pay for small reductions in risks of death in Sao Paulo. As discussed in the literature review, another metric has been discussed among environmental economists in the context of air pollution. This is the value of a statistical life year (VSLY), which arguably has a number of advantages over the value of a statistical life (e.g. Markandya *et al.*, 2003; Alberini *et al.*, 2004a). Rabl (2003) proposed a key argument in this debate. He shows that the number of deaths that can be attributed to this cause is only observable in mortality statistics when the exposure-death effect is sufficiently instantaneous that the initial increase in death rate is not obscured by the subsequent depletion of the population who would otherwise die later. Rabl argues that the usual case is that the impact of air pollution is not instantaneous but the cumulative result after years of exposure, so that the number of deaths is not observable[76]. As a result, it is impossible to tell whether a given exposure has resulted in a small number of people losing a large amount of life expectancy or a large number of people losing a small amount of life expectancy. In this case only the average number of years of life lost are calculable and

(approximately 50%) for all income-level groups, except the highest two out of eight groups (class A).

[76] In this case, for example, affected individuals may die over a period of 30 years following exposure. Some individuals may die in the second year of this period who would have died anyway in year 20. But individuals may die in year 20 from the exposure. Any change in the observable mortality rate in year 20 therefore understates the true mortality rate that can be attributable to air pollution.

so this makes a strong case for the use of VSLY in the context of air pollution (Markandya *et al.*, 2003).

In order to compute the value of a statistical life year it is necessary to convert the probability changes of 1 in 1000 and 5 in 1000 into changes in life expectancy. For Europe, Rabl (2001) derived the changes in remaining life expectancy associated with the 5-in-1000 risk change over the next 10 years based on empirical life tables. According to his calculations, the extension in life expectancy ranges from 0.64 to 2.02 months, depending on the person's age and gender, and averages 1.23 months (37 days) for a European sample (Alberini *et al.*, 2004a). Similar figures were estimated for Brazil following Rabl (2001). The extension in life expectancy ranged between 0.12 and 1.92 for individuals aged between 40 and 70 years old. For an average individual in our sample (56 years old) this figure is equal to 0.96 months or approximately 29 days.

Table 47: Weibull accelerated failure-time model: willingness to pay for one month of life extension

	Total sample		Flag0 = 0		Flag4 = 0	
Regressors	Coefficient	Robust standard errors	Coefficient	Robust standard errors	Coefficient	Robust standard errors
	5-in-1000 immediate risk reduction					
Constant	8.0512(*)	0.1125	8.1120(*)	0.1380	7.9572(*)	0.1174
Ancillary parameter (p)	0.6213	0.0387	0.6014	0.0422	0.6335	0.0479
Log likelihood	-467.9662		-340.2666		-408.7986	
N	240		172		213	

Notes: Flag0 = Inconsistent maximum willingness-to-pay responses for both immediate risk reductions.
Flag4 = Wrong answer to both probability tests.

To estimate the value of a life-expectancy extension of a month, the respondent's willingness to pay was divided by that respondent's life expectancy extension and re-estimated using the Weibull double-bound constant-only model (Table 47). The resulting mean willingness to pay equates to US$1,329 per year for each month of additional life expectancy (total sample). Median willingness to pay by the same method is US$512 for a month of life expectancy gain. Because in our survey the payments would be made every year for ten years, the total willingness-to-pay figures for a life expectancy gain of one month are US$13,288 and US$5,116 respectively. The implied values of a statistical life year (VSLY) are US$159,456 and US$61,392, respectively. Similar figures obtained when excluding 'yeah-saying' respondents correspond to VSLY equal to US$62,944 and US$34,729. Table 48 shows the results obtained using all sub-samples.

Table 48: Value of a statistical life year (VSLY) – 5-in-1000 immediate risk reduction – Weibull distribution

	Sample *including* 'yeah-saying' respondents		
	Total sample	Flag0	Flag4
Mean	159,456	176,515	141,811
Median	61,392	63,979	56,522
	Sample *excluding* 'yeah-saying' respondents		
Mean	62,944	62,396	55,961
Median	34,729	34,404	32,954

US$ 1 = R$ 3.40 during the survey period (March/2003).

5.9. Conclusions

This study used a methodology recently developed in North America, and applied a contingent valuation survey instrument that was designed to estimate the willingness to pay for reducing an individual's risk of death. This instrument was adapted to the particularities of the Brazilian context and used to estimate the willingness to pay for different reductions in probabilities of death, regardless of the context in which the risks are analysed. The results suggest a value of a statistical life ranging between US$0.77 and 6.1 million, while it is suggested for policy analyses in Brazil that conservative values ranging between US$0.77 and US$1.31 million be used. The suggested value of a statistical life year ranged between US$ 61,392 and US$ 159,456.

However, a number of problems seem to suggest that these figures are higher than would be expected for a middle-income country like Brazil. The most important problem that could be identified in this study refers to the 'yeah-saying' behaviour observed in some of the respondents. The results using a sub-sample that does not include potential 'yeah-saying' respondents suggest a value of a statistical life ranging between US$415,831 and US$489,752, and the value of a statistical life year ranging between US$34,729 and US$62,944.

As in the studies for industrialised countries, there are problems in eliciting the willingness to pay for risks of the kind experienced through air pollution. The issues that need most attention are (a) determining the survey design that minimises the possibility of 'yeah-saying' behaviour among the respondents (b) getting the idea of probabilities across to a wider section of the population and (c) understanding why willingness to pay for different risk levels does not behave consistently in line with expectations (proportionality). Finally, the analysis of the results and problems faced during this valuation exercise can be helpful for future developments of contingent valuation studies in developing countries.

6. Research questions

The literature review of epidemiologic studies suggested that the mortality impact of air pollution tends to be more significant among the elderly and/or those individuals in poor health (the harvesting effect). When analysing the benefits of policies that aim to reduce air pollution, economists should consider that the willingness to pay for a reduction in the risk of dying might differ between young and old individuals, and between healthy and impaired groups. The theoretical literature review showed that these issues are inconclusive from a theoretical perspective (discussed below), and have to be solved empirically.

One aim of this research has been to estimate what adults in Brazil are willing to pay to reduce their risk of dying, through a contingent valuation survey described in Chapter 4, and to compare the results with related studies conducted in developed countries, which is discussed in Chapter 3. In addition, the main research questions involve examining the impact – if any – of age and current health status on willingness-to-pay estimates for small risk reductions in Brazil; and investigating whether willingness to pay for reduced future risks to death in Sao Paulo corresponds to expectation and theory.

This chapter discusses the research questions described above and is organised as follows. Section 6.1 investigates the impact of age on willingness-to-pay estimates, while section 6.2 explores the impact of health status. Section 6.3 presents the willingness-to-pay estimates for a future mortality risk reduction – chronic mortality – and section 6.4 discusses differences between results obtained in Brazil and those obtained in European and North American studies. All the tests are performed using both final and pilot samples in order to test whether the results are sample-independent (robust). In addition, all the sub-samples are tested; that is, the sample where respondents who failed the probability tests are excluded (flag4), the sample where respondents who provided inconsistent willingness-to-pay responses are excluded (flag0), and the total sample. Finally, all the tests were also performed on a sample that does not include the 'yeah-saying' respondents, a bias identified in the results discussed in the last chapter.

6.1. The impact of age on willingness-to-pay estimates

Theory is inconclusive about the role of age in the willingness to pay for small reductions in probabilities of death and the value of a statistical life, as demonstrated in the theoretical literature review. Initially, it can be expected that willingness to pay will increase with the probability of dying during the following year (baseline risk), which increases with age. However, willingness to pay also depends on the marginal utility of future consumption, and it is not clear whether and how this can be influenced by age (Alberini *et al.*, 2004b). For plausible parameter values, however, Shepard and Zeckhauser (1982) concluded that willingness to pay would follow an inverted-U shape with regard to age, when assuming a very specific functional form for the utility function. Krupnick *et al.*, (2002) showed that willingness-to-pay estimates did not change with age in Canada, although estimates for individuals older than 70 years were lower than for the rest of the sample (but not statistically significant). Alberini *et al.*, (2004b) found no age effects on the willingness-to-pay estimates for reductions in risk of death in the US.

In this section an analysis is developed to investigate the impact of respondents' age on willingness-to-pay estimates in Brazil. Initially, different models were developed in order to identify the significance of age variables when explaining willingness to pay. That is, willingness to pay is regressed in models where age (model 1), age-square (model 2), and age-category dummies (model 3) are the only regressors. These models, suggested by Krupnick *et al.*, (2002), show the effect that marginal changes on the regressors have (*ceteris paribus*) on willingness to pay. Model 1 imposes a linear relationship between age and willingness to pay, while model 2 includes the quadratic functional form. Model 3 specifies dummy variables per age category, which enables the investigation of the shape of the willingness-to-pay curve against respondents' age. In mathematical form:

$$\begin{aligned}
&\text{Model 1} \qquad \log WTP_i = \alpha + \beta.age_i + \varepsilon_i \\
&\text{Model 2} \qquad \log WTP_i = \alpha + \beta_1.age_i + \beta_2.(age_i)^2 + \varepsilon_i \qquad (106) \\
&\text{Model 3} \qquad \log WTP_i = \alpha + \beta_1.dummy5059_i + \beta_2.dummy6069_i + \beta_3.dummy7075_i + \varepsilon_i
\end{aligned}$$

6.1.1. Final sample

The total sample (without excluding any inconsistencies) and sub-samples excluding individuals with poor understanding of the concept of probabilities (Flag4) and those who stated inconsistent willingness-to-pay responses (Flag0) were used. These analyses used only the responses for the 5-in-1000 immediate risk reduction because it was the first question presented to respondents, and arguably, the one they answered with more attention and accuracy[77].

As can be seen in Table 49, none of the coefficients of the age variable, which is a continuous variable ranging from 40 to 75, was statistically significant[78]. The results confirm the findings of the validity tests of willingness-to-pay estimates performed in Chapter 5 (the age variable was not significant as well). During the validity tests, the lack of significance of coefficients of the age variable might have been influenced by the inclusion of other socio-economic and attitudinal variables, especially the respondents' income. By specifying age as the only regressor to explain willingness to pay, it is possible to analyse the effect of age on willingness to pay without the influence of other variables.

Table 49: Impact of age on willingness-to-pay for a 5-in-1000 immediate risk reduction – final sample – Model 1

Weibull model	Total sample		Flag0		Flag4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	7.38382(*)	0.55744	7.57496(*)	0.66273	7.63937(*)	0.63847
Age	0.00407	0.00993	0.00184	0.01183	-0.00070	0.0116
Scale parameter	1.194233		1.229878		1.216734	
N	240		172		213	
Log likelihood	-404.43428		-295.57934		-361.84045	
Excluding 'yeah-saying' respondents						
Constant	6.91551(*)	0.37336	7.03440(*)	0.41638	7.14553(*)	0.40168
Age	-0.00170	0.00631	-0.00360	0.00712	-0.00654	0.00680
Scale parameter	0.7043396		0.7283336		0.6971915	
N	101		87		89	
Log likelihood	-124.3297		-109.89914		-108.28223	

Notes: (*) significant at 1%; (**) significant at 10%.

The same non-significant results are obtained when a specification including the quadratic form of the age variable is used (Table 50). However, the coefficients are all statistically significant at the 10% level when respondents that expressed inconsistent willingness-to-pay answers are excluded from the sample (Flag0). It can be interpreted from the signs of the age variables' coefficients (negative for age and positive for age

[77] The 1-in-1000-risk reduction question is asked after the 5-in-1000-risk reduction question. Prior testing in the North American context indicated that answers to the second question tend to be less reliable than those to the first question. It is also likely to be an easier size of risk change to effectively comprehend.

[78] The same results were obtained when model 1 was specified using age square only.

square) that for this group of respondents, willingness to pay decreases with age but the slope of this relationship increases at higher ages[79].

Table 50: Impact of age on willingness-to-pay for a 5-in-1000 immediate risk reduction – final sample – Model 2

Weibull model	Total sample		Flag0		Flag4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	10.7317(*)	2.95846	13.9206(*)	3.66949	10.0997(*)	3.58184
Age	-0.11740	0.10767	-0.2268(**)	0.13191	-0.09070	0.13333
Age square	0.00107	0.00096	0.0020(**)	0.00117	0.00080	0.00122
Scale parameter	1.188735		1.214908		1.212641	
N	240		172		213	
Log likelihood	-403.76362		-294.03514		-361.55688	
Excluding 'yeah-saying' respondents						
Constant	8.97921(*)	2.05523	8.96120(*)	2.27127	7.31402(*)	2.20197
Age	-0.07654	0.07386	-0.07309	0.081124	-0.01264	0.07866
Age square	0.00066	0.00065	0.00061	0.00071	0.00005	0.00068
Scale parameter	0.7030674		0.727204		0.6973341	
N	101		87		89	
Log likelihood	-123.956		-109.6372		-108.28014	

Notes: (*) significant at 1%; (**) significant at 10%.

Table 51: Impact of age on willingness-to-pay for a 5-in-1000 immediate risk reduction – final sample – Model 3

Weibull model	Total sample		Flag0		Flag4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	7.73582(*)	0.17290	7.90024(*)	0.20315	7.77143(*)	0.17434
Age 50-59	-0.31009	0.22105	-0.4337(**)	0.25801	-0.35847	0.22969
Age 60-69	-0.16486	0.23917	-0.39622	0.28792	-0.23252	0.24946
Age 70-75	0.19189	0.37543	0.29302	0.42406	0.09430	0.49614
Scale parameter	1.176243		1.193981		1.196425	
N	240		172		213	
Log likelihood	-402.34981		-291.79582		-359.89993	
Excluding 'yeah-saying' respondents						
Constant	6.78902(*)	0.13488	6.81217(*)	0.15354	6.78243(*)	0.13962
Age 50-59	0.15795	0.17441	0.17003	0.19034	0.19899	0.17997
Age 60-69	-0.15217	0.17175	-0.20616	0.19814	-0.24073	0.18217
Age 70-75	0.28613	0.18684	0.25628	0.21142	0.13264	0.20489
Scale parameter	0.6873942		0.7088493		0.6752485	
N	101		87		89	
Log likelihood	-121.93827		-107.4906		-105.55861	

Notes: (*) significant at 1%; (**) significant at 10%.

Table 51 shows the results of the third specification model used to investigate the pattern of willingness to pay in regard to respondents' age. The coefficients of the

[79] The significant parameters obtained in Table 50 (model 2 and sub-sample Flag0) were used to estimate willingness to pay per age resulting in decreasing WTP (minimum value at age 56), and

dummy variables indicating age groups were in general statistically insignificant. An exception was the coefficient for the group 50 to 59 years old respondents when individuals that reported inconsistent willingness-to-pay responses were excluded (Flag0). The results suggest that willingness to pay decreases with age but increases in older ages – the negative sign of coefficients for age groups 50-59 and 60-69 indicates that individuals in these age groups pay less than respondents aged 40-49, the excluded dummy. This result, however, is undermined by the low significance of the coefficients.

6.1.2. Pilot sample

The same analyses/models were developed using the pilot sample to investigate whether the results are confirmed when a different sample is used. That is, it is intended to investigate whether the impact of age on willingness-to-pay estimates remain the same when another sample of residents of Sao Paulo is used. As demonstrated in Chapter 5, these samples differ in terms of education and income levels. The pilot sample has a considerable share of its respondents composed of high-level employees of a bank, and students of a University for the Third Age in Sao Paulo. Table 52, Table 53 and Table 54 show the results.

Table 52: Impact of age on willingness-to-pay for a 5-in-1000 immediate risk reduction – pilot sample – Model 1

Weibull model	Total sample		Flag0		Flag4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	8.64332(*)	0.51778	9.00147(*)	0.53433	8.56147(*)	0.53086
Age	0.00003	0.00873	-0.00328	0.00893	0.00153	0.00897
Scale parameter	1.708479		1.653056		1.708488	
N	305		254		286	
Log likelihood	-644.37448		-532.57102		-604.32827	
Excluding 'yeah-saying' respondents						
Constant	5.65513(*)	0.34681	5.66358(*)	0.37771	5.63225(*)	0.36750
Age	-0.00825	0.00594	-0.00857	0.00649	-0.00860	0.00647
Scale parameter	0.5477003		0.5658422		0.5791783	
N	65		54		59	
Log likelihood	-66.456553		-57.057667		-62.843895	

Notes: (*) significant at 1%; (**) significant at 10%.

In terms of statistical significance of the coefficients of model 1, the results are identical between the pilot and final survey (Table 52 and Table 49), that is, all coefficients are insignificant. The difference is the inverted sign of variable age when

increasing WTP at higher ages (U-shape).

the cleaned sub-samples are considered, although the lack of significance of the coefficients makes the analysis of their signs not relevant.

Table 53: Impact of age on willingness-to-pay for a 5-in-1000 immediate risk reduction – pilot sample – Model 2

Weibull model	Total sample		Flag0		Flag4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	4.57486	2.96735	5.32429(**)	3.03639	4.71422	3.05159
Age	0.14570	0.10325	0.12799	0.10525	0.13980	0.10656
Age square	-0.00126	0.00087	-0.00113	0.00089	-0.00120	0.00090
Scale parameter	1.700634		1.646506		1.701412	
N	305		254		286	
Log likelihood	-643.51614		-531.94023		-603.60593	
Excluding 'yeah-saying' respondents						
Constant	3.62538(**)	1.77772	3.40768(**)	2.01424	4.36592(**)	1.98380
Age	0.06535	0.06245	0.07286	0.07020	0.03753	0.07052
Age square	-0.00064	0.00054	-0.00071	0.00060	-0.00040	0.00061
Scale parameter	0.5430748		0.5592438		0.5772879	
N	65		54		59	
Log likelihood	-65.962099		-56.543749		-62.690994	

Notes: (*) significant at 1%; (**) significant at 10%.

Again, the results of the pilot sample are insignificant as they were with the final sample, but the signs of the coefficients in the model are inverted. The signs of the coefficients in Table 53 indicate that the coefficient of variables age are positive and the squared age terms are negative, suggesting that willingness to pay increases with age but the slope of this relationship decreases at higher ages. This may be a consequence of the differences in education and income levels in the pilot sample, although the signs of coefficients have to be analysed with care given the lack of statistical significance.

Table 54 shows that the coefficients of the dummy variables indicating age groups continue to be statistically insignificant using the pilot sample. Again the signs are inverted when compared with the signs obtained in the final sample. The signs of the coefficients in Table 54 suggest that willingness to pay increases with age, although the result is the opposite when the 'yeah-saying' respondents are excluded from the pilot sample.

In summary, the results of this analysis of the effect of the respondents' age on the willingness to pay for a small reduction in risk of death confirm the results obtained in the validity tests of the willingness-to-pay estimates undertaken in Chapter 5, which suggests that the respondents' age was not important in determining the willingness-to-pay responses. This result is in line with other recent contingent valuation studies developed in Europe and North America (e.g. Alberini *et al.*, 2002; Markandya *et al.*, 2003).

Table 54: Impact of age on willingness-to-pay for a 5-in-1000 immediate risk reduction – pilot sample – Model 3

Weibull model	Total sample		Flag0		Flag4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	8.50534(*)	0.17544	8.71871(*)	0.18537	8.49831(*)	0.17831
Age 50-59	0.26772	0.25837	0.24647	0.26555	0.27343	0.26963
Age 60-69	0.18567	0.24408	0.06069	0.24926	0.20594	0.24875
Age 70-75	0.09242	0.24926	0.04779	0.25349	0.12794	0.25718
Scale parameter	1.702197		1.647841		1.702295	
N	305		254		286	
Log likelihood	-643.79974		-532.16748		-603.76607	
Excluding 'yeah-saying' respondents						
Constant	5.25186(*)	0.11629	5.24684(*)	0.12151	5.23786(*)	0.11779
Age 50-59	0.02104	0.13772	0.01519	0.15425	-0.04465	0.15433
Age 60-69	-0.14648	0.15307	-0.14951	0.17129	-0.17879	0.17226
Age 70-75	-0.31769	0.21084	-0.31701	0.21286	-0.28820	0.23238
Scale parameter	0.5435866		0.5604402		0.577837	
N	65		54		59	
Log likelihood	-66.026004		-56.708836		-62.750088	

Notes: (*) significant at 1%; (**) significant at 10%.

6.1.3. Willingness-to-pay estimates per age-group

The results in Brazil suggest that age is not statistically significant in explaining willingness to pay for an immediate 5-in-1000 risk reduction. Although not significant, the coefficients for categorical dummy variables (model 3, both pilot and final samples) do not suggest an inverted-U-shape of the willingness-to-pay curve as proposed by Shepherd and Zeckhauser (1982). However, the results using the final sample suggest that individuals aged 70 or more tend to pay more compared to individuals aged 40 to 50 (the dummy excluded from model 3), while the results using the pilot sample indicate willingness to pay increasing with age[80].

In order to further investigate that, it is proposed to estimate mean and median willingness to pay for different sub-samples according to age groups. This approach is not affected by the poor statistical performance of the age variable since the constant-only approach (Weibull distribution) is used, that is, willingness to pay is modelled with no regressor. These estimates can provide further evidence of how willingness to pay

[80] Based on the positive signs of the coefficients of variable age at models 1, 2 and 3 (Table 52 and Table 53).

varies with age. Mean and median willingness to pay are estimated using the final sample and the pilot sample.

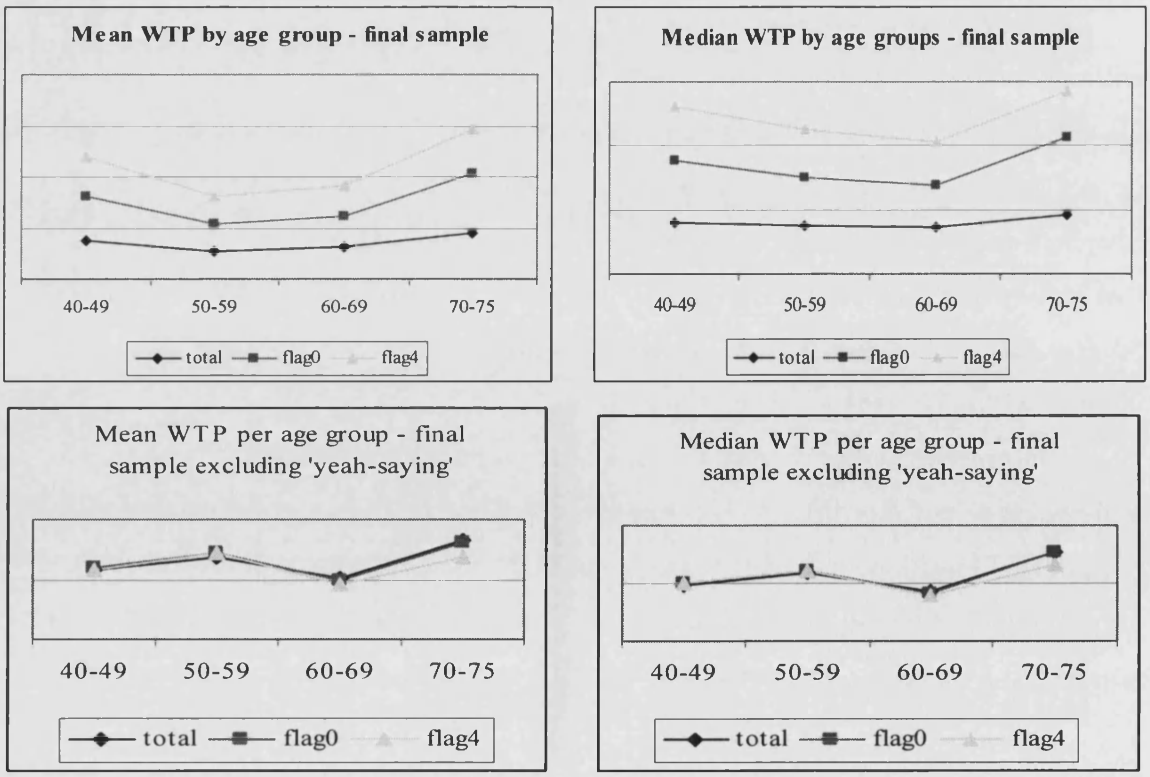
As can be seen in Table 55 and Figure 2, both mean and median willingness-to-pay estimates follow a U-shape trend when the final sample is used. Mean willingness to pay initially decreases with age but then increases steadily to a level higher than the willingness to pay expressed by the youngest group. Median willingness-to-pay estimates vary less according to age than mean values, but the pattern is similar – initially decreasing and then increasing.

Table 55: Mean and median annual willingness to pay per age group (US$ 2003) – 5-in-1000 risk reduction starting now – final sample

	Mean			Median		
Age group	Total sample	Flag0	Flag4	Total sample	Flag0	Flag4
40 – 49	734.59	875.45	769.08	401.92	477.41	429.25
50 – 59	531.50	557.16	528.84	370.69	383.74	369.95
60 – 69	621.85	588.28	609.54	362.21	324.25	342.80
70 – 75	891.21	1,176.95	843.47	453.95	614.45	353.10
40 – 64	612.32	655.02	629.49	374.47	394.54	383.21
65 – 75	796.99	918.29	744.06	419.10	445.92	354.05

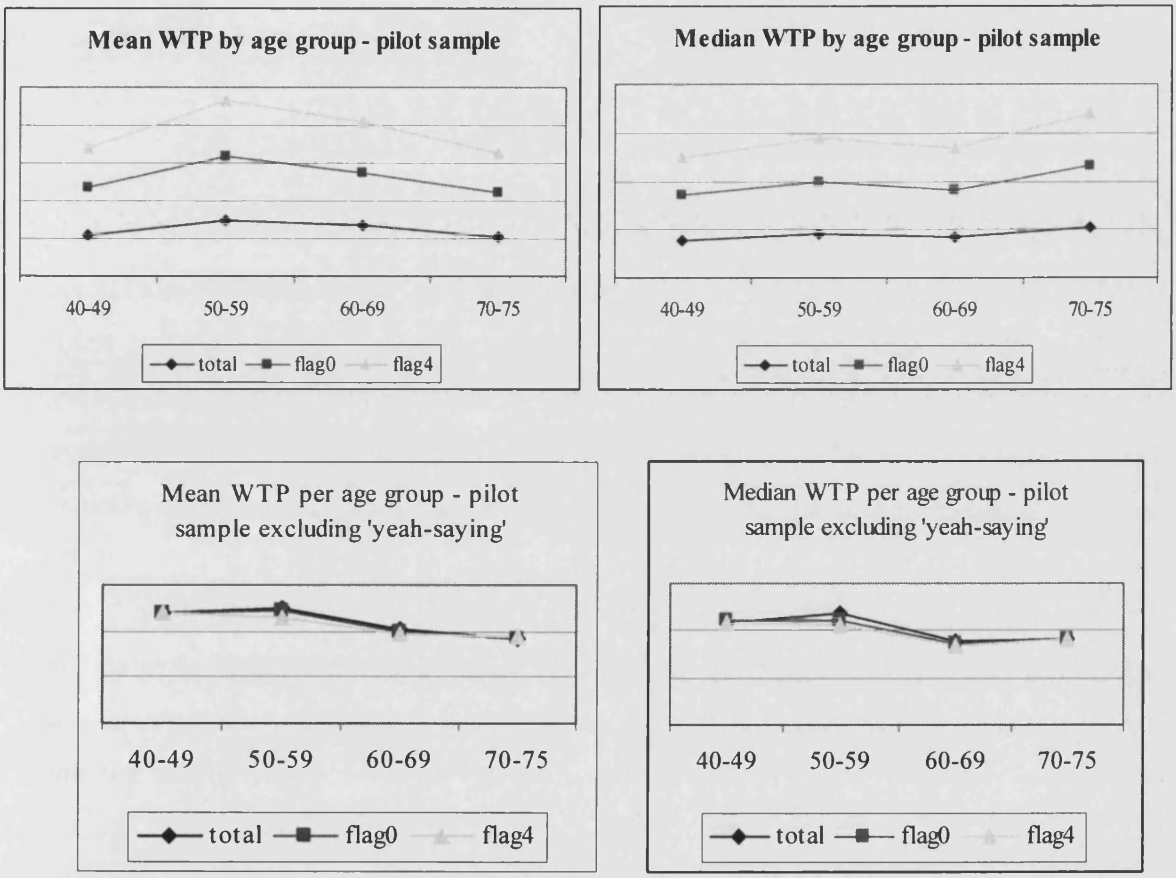
US$ 1 = R$ 3.40 during the survey period (March/2003).

Figure 2: Mean and median willingness-to-pay estimates by age groups – final sample



The same analysis was performed using the pilot sample in an attempt to confirm whether the pattern of willingness-to-pay estimates by age groups remains the same. Although the values of both sets of estimates cannot be compared – the bid values offered in the pilot sample were different (lower) than those used in the final sample – the willingness-to-pay curve can be identified in relation to the respondents' age using the pilot sample and compared to the same curve originated from the final sample.

Figure 3: Mean and median willingness-to-pay estimates by age groups – pilot sample



As can be seen in Figure 3, mean willingness to pay has the inverted-U shape proposed by Shepherd and Zeckhauser (1982), the opposite obtained when using the final sample. Median willingness to pay also differs from the pattern presented with the final sample. These facts suggest that in the Brazilian case, the effect of age on willingness-to-pay estimates is sample-dependent, and has no identifiable pattern.

6.1.4. Final comments

It can be concluded that no clear age effect on the willingness to pay for small risk reductions in Brazil can be identified from the samples available. The lack of statistical significance of coefficients of the age variable in models explaining the willingness-to-pay responses undermines any conclusion about the effect of age on willingness to pay. In addition, mean and median willingness to pay for different age groups, which were estimated using the constant-only approach, had no consistent pattern between both samples, which reinforces the conclusion that no effect can be identified.

6.2. The impact of health status on willingness-to-pay estimates

Theoretically, health status has a similar approach as age with regard to mixed influences on willingness to pay. Initially, it can be expected that individuals in poor health tend to pay more for a given reduction in their mortality risk since those individuals have lower chances of surviving the current period (higher baseline risk). On the other hand, these individuals have a lower life expectancy, which may imply lower willingness to pay for reductions in the risk of death, depending on the influence of health status on the utility of future consumption. Thus, the effect of respondents' and/or their relatives' health statuses on the value of a statistical life cannot be determined according to theory. Empirically, Alberini *et al.* (2004b) found that willingness to pay for reductions in risks of death are significantly greater for individuals with high blood pressure in the US, and that chronic respiratory illness and heart disease have no significant effect on willingness to pay both in Canada and the US.

The validity tests of willingness to pay performed in Chapter 5 showed that only two SF36[81] indices were statistically significant in explaining willingness-to-pay responses, while other expected factors were not (e.g. having visited an emergency-room in the last five years and having cases of cancer in the family). These results might have been affected by the influence of other covariates used in the validity test of willingness-to-pay estimates. As in the analysis of the impact of age on willingness to pay for reductions in the risk of death, three different models were specified including

[81] Short Form 36, or SF-36. Ware, J.E.Jr., Kosinski, M. and Keller, S. (1997). *SF-36 Physical and Mental Health Summary Scales: a user's guide manual.* Lincoln: RI Quality Metric.

the most important variables available in the dataset. Those variables represent the respondents' own health status and the occurrence of some important diseases in the respondents' relatives. Model 1 includes dummy variables reflecting the occurrence of the main diseases associated with air pollution – respiratory and cardiac diseases and cancer – either for the respondent and/or his or her family. Model 2 tests if the fact of having visited an emergency room or having a hospital admission in the previous five years has an influence on the willingness to pay for reductions in the probability of death. Finally, model 3 investigates the SF36 health indices. In mathematical form:

$$\begin{array}{ll} \text{Model 1} & \log WTP_i = \alpha + \beta_1.cardiac_i + \beta_2.respiratory_i + \beta_3.cancer_i + \varepsilon_i \\ \text{Model 2} & \log WTP_i = \alpha + \beta_1.selfhealth_i + \beta_2.ER_i + \varepsilon_i \\ \text{Model 3} & \begin{array}{l} \log WTP_i = \alpha + \beta_1.mhs_i + \beta_2.pfs_i + \beta_3.rlps_i + \beta_4.ps_i + \\ + \beta_5.ghs_i + \beta_6.evs_i + \beta_s.sfs_i + \beta_8.rles_i + \beta_9.chs_i + \varepsilon_i \end{array} , \end{array} \tag{107}$$

where,

mhs mental health score;

pfs physical function score;

rlps role limitation score;

ps pain score;

ghs general health perception score;

evs energy vitality score;

sfs social functioning score;

rles role limitation emotional score;

chs change in health score[82].

6.2.1. Final sample

Table 56 shows the results obtained with model 1. As can be seen, none of the coefficients are statistically significant in most of the sub-samples tested – except the cancer variable when 'yeah-saying' and inconsistent respondents are excluded. This result suggests that the occurrence of these health diseases in the respondents' families or for themselves does not affect their willingness to pay for a reduction in their probability of death. In addition, it confirms the results of the validity tests of the willingness-to-pay estimates in Chapter 5, that is, other regressors in the validity tests did not affect these health indictors. The negative signs of coefficients relating to cancer

[82] For a full description of the health status indices the reader may refer to Krupnick *et al.* (2002), annex.

and respiratory diseases indicate that respondents (or their families) who experienced these diseases tend to express lower willingness to pay. The positive sign for cardiac diseases suggests the opposite. Both results cannot be claimed as relevant given their poor statistical significance.

Model 2 is presented in Table 57, demonstrating a similar lack of statistical significance of the coefficients obtained in model 1. No willingness-to-pay effect can be identified in relation to the visit to an emergency room, hospitalisation or the self-assessed current health status.

Table 56: Impact of health status on willingness-to-pay for a 5-in-1000 immediate risk reduction – final sample – Model 1

Weibull model	Total sample		Flag 0		Flag 4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	7.62652$^{(*)}$	0.16094	7.61263$^{(*)}$	0.19063	7.62346$^{(*)}$	0.17310
Occurrence of cardiac disease (own and/or family)	0.10949	0.19512	0.20253	0.23506	0.13436	0.20436
Occurrence of respiratory disease (own and/or family)	-0.21946	0.19846	-0.06622	0.23316	-0.33921	0.21466
Occurrence of cancer (own and/or family)	-0.05555	0.19028	-0.13794	0.23828	-0.01026	0.20979
Scale parameter	1.190826		1.225911		1.207066	
N	240		172		213	
Log likelihood	-403.73177		-294.95051		-360.23016	
Excluding 'yeah-saying' respondents						
Constant	6.87884$^{(*)}$	0.11639	6.88231$^{(*)}$	0.12148	6.84119$^{(*)}$	0.12561
Occurrence of cardiac disease (own and/or family)	-0.05107	0.13985	-0.03695	0.15152	-0.00367	0.14318
Occurrence of respiratory disease (own and/or family)	0.09196	0.14135	0.15790	0.15958	0.00285	0.15159
Occurrence of cancer (own and/or family)	-0.20592	0.14529	-0.276$^{(**)}$	0.16210	-0.25127	0.16107
Scale parameter	0.6958		0.7153746		0.6915032	
N	101		87		89	
Log likelihood	-123.32829		-108.57904		-107.5456	

Notes: (*) significant at 1%; (**) significant at 10%.

As can be seen in Table 58, only a few health indices were statistically significant when explaining willingness-to-pay responses, among them the physical function score and the role limitation score. The result is not consistent among all sub-samples. The positive sign of the parameters suggests that the healthier the respondent feels (physically) the more this respondent would like to pay for a reduction in his or her risk of dying. The same interpretation can be obtained from the positive sign of the role limitation physical score. This result is in contrast with the result in model 2, where the self-assessed health status of the individual was not significant in explaining variations in willingness-to-pay responses. Perhaps individuals tend to value extensions in life expectancy more if they believe they are in good health; as if it was not worth paying for an increase in risk of surviving if the individual is not in good health. However, the result of the subjective health status (self-assessed) was not significant, while some health indices were significant. The health indices are constructed from individuals' responses to questions about their daily activities. In this sense, the health indices can be considered a subjective measure of health quality as well.

Table 57: Impact of health status on willingness-to-pay for a 5-in-1000 immediate risk reduction – final sample – Model 2

Weibull model	Total sample		Flag 0		Flag 4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	7.66659(*)	0.20486	7.65733(*)	0.27844	7.61255(*)	0.22630
Self-assessed health status	-0.00902	0.10309	0.03017	0.14109	0.01185	0.11526
Has visited an emergency room or hospital during the last five years	-0.20758	0.19849	-0.18753	0.23719	-0.18647	0.22161
Scale parameter	1.190384		1.226333		1.212699	
N	240		172		213	
Log likelihood	-404.02199		-295.28819		-361.49529	
Excluding 'yeah-saying' respondents						
Constant	6.94380(*)	0.15689	6.93623(*)	0.18381	6.91936(*)	0.16733
Self-assessed health status	-0.07893	0.07438	-0.07007	0.09339	-0.08659	0.07908
Has visited an emergency room or hospital during the last five years	0.08760	0.15899	0.08844	0.20470	0.06303	0.18695
Scale parameter	0.6999923		0.7261699		0.695082	
N	101		87		89	
Log likelihood	-123.85413		-109.68437		-108.15056	

Notes: (*) significant at 1%; (**) significant at 10%.

Table 58: Impact of health status on willingness-to-pay for a 5-in-1000 immediate risk reduction – final sample – Model 3

Weibull model	Total sample		Flag 0		Flag 4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	7.24430(*)	0.53509	7.19303(*)	0.64744	6.97240(*)	0.59985
Mental health score	0.00215	0.00694	0.00728	0.00839	0.00016	0.00711
Physical function score	0.00707(*)	0.00251	0.00858(**)	0.00337	0.00697(*)	0.00266
Role limitation physical score	0.00724(*)	0.00233	0.00617(**)	0.00307	0.00982(*)	0.00242
Pain score	-0.00168	0.00546	0.00371	0.00680	0.00067	0.00595
General health perception score	-0.00371	0.00612	-0.00807	0.00725	-0.00555	0.00654
Energy vitality score	-0.00993	0.00646	-0.01167	0.00752	-0.00871	0.00722
Social functioning score	0.00041	0.00647	-0.00007	0.00903	0.00115	0.00704
Role limitation emotional score	0.00009	0.00247	-0.00190	0.00308	0.00036	0.00249
Change in health score	0.00182	0.00372	-0.00091	0.00501	0.00086	0.00445
Scale parameter	1.148338		1.188389		1.156018	
N	240		172		213	
Log likelihood	-395.56777		-289.70854		-351.67216	
Excluding 'yeah-saying' respondents						
Constant	6.59323(*)	0.37088	6.59697(*)	0.44115	6.26763(*)	0.38270
Mental health score	-0.00055	0.00423	0.00140	0.00535	0.00352	0.00368
Physical function score	0.00859(*)	0.00276	0.00865(*)	0.00295	0.01033(*)	0.00236
Role limitation physical score	0.00162	0.00249	0.00119	0.00295	0.00166	0.00252
Pain score	-0.00745(**)	0.00395	-0.00693	0.00466	-0.00579	0.00384
General health perception score	0.00786	0.00483	0.00956(**)	0.00547	0.01046(**)	0.00435
Energy vitality score	-0.00102	0.00532	-0.00062	0.00630	-0.00537	0.00528
Social functioning score	0.00125	0.00392	-0.00326	0.00574	0.00164	0.00403
Role limitation emotional score	-0.00346	0.00247	-0.00207	0.00281	-0.00341	0.00231
Change in health score	-0.00383	0.00361	-0.00492	0.00418	-0.0074(**)	0.00414
Scale parameter	0.6597953		0.6834068		0.6159109	
N	101		87		89	
Log likelihood	-117.41214		-104.02463		-98.454183	

Notes: (*) significant at 1%; (**) significant at 10%.

6.2.2. Pilot sample

The aim of using the pilot sample to test the models above is to investigate if the results obtained using the final sample are robust, that is, not dependent on the sample. The most interesting result in Table 59 is the marginal significance of the coefficients associated with cases of cancer and cardiac diseases, although this result is not consistent among all sub-samples, neither in accordance with the results using the final sample. The results suggest that respondents who have had cancer or have had a case of cancer in their family pay more to reduce their risk of dying. This result is not confirmed when 'yeah-saying' respondents are excluded from the analysis.

Table 59: Impact of health status on willingness-to-pay for a 5-in-1000 immediate risk reduction – pilot sample – Model 1

Weibull model	Total sample		Flag 0		Flag 4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	8.37705(*)	0.18256	8.51486(*)	0.19485	8.31107(*)	0.19093
Occurrence of cardiac disease (own and/or family)	0.23343	0.19841	0.29683	0.20721	0.35370(**)	0.20764
Occurrence of respiratory disease (own and/or family)	-0.09766	0.19312	-0.02012	0.19904	-0.09918	0.19859
Occurrence of cancer (own and/or family)	0.41140(**)	0.19735	0.28203	0.19922	0.38889(**)	0.20563
Scale parameter	1.689512		1.64072		1.685224	
N	305		254		286	
Log likelihood	-641.39637		-530.55249		-600.80028	
Excluding 'yeah-saying' respondents						
Constant	5.25485(*)	0.10505	5.28855(*)	0.12523	5.24688(*)	0.11723
Occurrence of cardiac disease (own and/or family)	0.03270	0.11625	-0.03302	0.13969	-0.00626	0.12952
Occurrence of respiratory disease (own and/or family)	-0.03712	0.14043	-0.09082	0.17322	-0.01573	0.14718
Occurrence of cancer (own and/or family)	-0.2499(**)	0.13746	-0.21592	0.14535	-0.27989(**)	0.15081
Scale parameter	0.5460691		0.5672721		0.5744472	
N	65		54		59	
Log likelihood	-65.783115		-56.803394		-62.121039	

Notes: (*) significant at 1%; (**) significant at 10%.

Table 60 shows that the results of model 2 using the pilot are similar to those obtained using the final sample – non-significant coefficients for all covariates among all sub-samples. It is interesting to observe that the negative impact of having visited an emergency room or hospital admission is consistent with the previous result (Table 57), and this result is statistically significant when 'yeah-saying' respondents are excluded from the sample.

Table 60: Impact of health status on willingness-to-pay for a 5-in-1000 immediate risk reduction – pilot sample – Model 2

Weibull model	Total sample		Flag 0		Flag 4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	8.54827(*)	0.22627	8.74137(*)	0.22971	8.51029(*)	0.23036
Self-assessed health status	0.06662	0.11532	0.05328	0.11697	0.08084	0.11748
Has visited an emergency room or hospital during the last five years	-0.16297	0.23623	-0.16848	0.24713	-0.06382	0.23869
Scale parameter	1.704696		1.65069		1.705007	
N	305		254		286	
Log likelihood	-644.09835		-532.40731		-604.12266	
Excluding 'yeah-saying' respondents						
Constant	5.29333(*)	0.11063	5.16331(*)	0.11544	5.21208(*)	0.11067
Self-assessed health status	-0.03138	0.05211	0.04595	0.04679	0.00224	0.05001
Has visited an emergency room or hospital during the last five years	-0.6331(**)	0.27090	-1.0645(*)	0.23586	-1.01058(*)	0.25179
Scale parameter	0.5356427		0.5181527		0.5400849	
N	65		54		59	
Log likelihood	-64.374915		-52.489327		-58.860414	

Notes: (*) significant at 1%; (**) significant at 10%.

Table 61 shows that a number of health indices are statistically significant in explaining variances in the willingness to pay when using the pilot sample, and this result is consistent across all sub-samples. These are the mental health, the physical function, the general health perception, and the social functioning scores. Compared to the final sample results, it confirms that the physical function score has a positive impact on willingness-to-pay estimates, that is, individuals with a higher physical score tend to pay more for reductions in their risk of death. On the other hand, the role-limitation physical score is not significant. When 'yeah-saying' respondents are excluded from the analysis the most interesting results refer to the significant and negative impact of the physical function score on the willingness-to-pay responses.

Table 61: Impact of health status on willingness-to-pay for a 5-in-1000 immediate risk reduction – pilot sample – Model 3

Weibull model	Total sample		Flag 0		Flag 4	
Regressors	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	8.16863(*)	0.67300	8.22114(*)	0.71904	8.45110(*)	0.67794
Mental health score	0.01722(**)	0.00738	0.01676(**)	0.00793	0.01539(**)	0.00766
Physical function score	0.01667(*)	0.00413	0.01359(*)	0.00462	0.01611(*)	0.00419
Role limitation physical score	0.00057	0.00330	-0.00391	0.00372	0.00078	0.00345
Pain score	-0.00258	0.00550	0.00193	0.00568	-0.00357	0.00555
General health perception score	-0.0144(**)	0.00760	-0.0151(**)	0.00797	-0.0170(**)	0.00754
Energy vitality score	0.00209	0.00791	0.00525	0.00839	0.00283	0.00790
Social functioning score	-0.0165(**)	0.00755	-0.0188(**)	0.00832	-0.0166(**)	0.00763
Role limitation emotional score	0.00405	0.00428	0.00666	0.00457	0.00553	0.00422
Change in health score	-0.00102	0.00451	0.00189	0.00475	-0.00136	0.00465
Scale parameter	1.621445		1.590087		1.622024	
N	305		254		286	
Log likelihood	-630.40866		-523.50916		-591.30871	
Excluding 'yeah-saying' respondents						
Constant	5.03422(*)	0.55029	4.64613(*)	0.79351	5.25249(*)	0.62382
Mental health score	0.00879(**)	0.00447	0.00388	0.00654	0.00931	0.00574
Physical function score	-0.00895(*)	0.00347	-0.01138(*)	0.00423	-0.01046(**)	0.00429
Role limitation physical score	-0.00060	0.00192	-0.00305	0.00217	-0.00097	0.00198
Pain score	-0.00403	0.00619	-0.00489	0.00779	-0.00529	0.00730
General health perception score	0.00238	0.00535	0.00120	0.00602	0.00041	0.00615
Energy vitality score	0.00409	0.00457	0.00860(**)	0.00514	0.00422	0.00550
Social functioning score	0.00018	0.00469	0.01081	0.01144	-0.00016	0.00478
Role limitation emotional score	0.00467(**)	0.00236	0.00654(**)	0.00292	0.00589(**)	0.00244
Change in health score	-0.00306	0.00259	-0.00340	0.00361	-0.00210	0.00301
Scale parameter	0.5023896		0.5166939		0.5226475	
N	65		54		59	
Log likelihood	-60.215361		-50.89318		-57.04763	

Notes: (*) significant at 1%; (**) significant at 10%.

6.2.3. Willingness-to-pay estimates per health occurrence

In order to investigate further whether particular health conditions affect willingness to pay for small risk reductions, mean and median willingness to pay are estimated using the constant-only Weibull distribution model[83] with the final sample. Sub-samples separated by health characteristics (e.g. cancer and non-cancer) are used

[83] The Weibull distribution was adopted in order to facilitate the comparison of results with the willingness-to-pay estimates shown in the last chapter, which were generated assuming the Weibull distribution.

and the willingness-to-pay estimates compared, providing more confidence in determining the role of specific health conditions in willingness-to-pay estimates.

Table 62: Mean and median annual willingness to pay per health groups (US$ 2003) – 5-in-1000 risk reduction starting now – final sample

Disease	Total sample		Flag0		Flag4	
	Yes	No	Yes	No	Yes	No
MEAN	653 (240)		712 (172)		654 (213)	
Cancer	632.84 (76)	663.03 (164)	656.56 (50)	734.93 (122)	652.48 (64)	654.59 (149)
Respiratory	574.07 (75)	689.98 (165)	708.52 (50)	713.42 (122)	529.19 (67)	712.33 (146)
Cardiac	662.57 (152)	637.81 (88)	759.16 (104)	640.92 (68)	664.34 (131)	637.45 (82)
ER	542.98 (45)	678.62 (195)	597.44 (30)	735.62 (142)	554.59 (38)	675.07 (175)
MEDIAN	384		405		377	
Cancer	379.36	385.67	368.49	420.47	375.98	376.84
Respiratory	339.46	405.28	407.27	403.86	307.55	412.48
Cardiac	388.34	375.49	431.57	366.37	381.16	369.31
ER	366.09	388.76	392.77	408.54	362.75	380.59
Excluding 'yeah-saying' respondents						
MEAN	245 (181)		249 (87)		234 (89)	
Cancer	212.52 (29)	257.78 (72)	209.23 (26)	265.73 (61)	194.98 (24)	248.77 (65)
Respiratory	253.43 (32)	240.90 (69)	264.82 (26)	242.16 (61)	231.34 (29)	235.85 (60)
Cardiac	238.06 (65)	257.23 (36)	241.81 (53)	260.26 (34)	230.05 (55)	241.41 (34)
ER	262.88 (17)	241.22 (84)	267.13 (12)	246.05 (75)	239.62 (15)	233.32 (74)
MEDIAN	208		208		199	
Cancer	184.86	217.93	179.32	221.92	169.16	211.65
Respiratory	217.77	203.44	223.46	202.09	197.00	200.50
Cardiac	201.37	220.23	198.92	223.46	195.28	206.14
ER	231.55	203.28	220.66	206.41	207.90	197.62

US$ 1 = R$ 3.40 during the survey period (March/2003). Sample sizes are in parenthesis.

The results in Table 62 confirm the signs of corresponding coefficients observed in Table 56 and Table 57. For example, a case of cancer observed in the respondent or his/her family is associated with lower willingness-to-pay estimates, the same being true for respiratory diseases and emergency-room visits and hospital admissions. Opposite results are associated with cardiovascular diseases. However, this result should be treated with care since none of these variables was statistically significant in regressions using the final sample – models 1 and 2.

6.2.4. Final comments

In summary, it can be concluded that no cancer, respiratory or cardiovascular disease effect can be identified in this study, given the lack of statistical significance of the coefficients in the regressions. However, the signs of the coefficients in regressions using the final sample (and the estimates in Table 62) suggest that the occurrence of respiratory (cardiac) diseases reduced (increased) the willingness to pay for a reduction in the probability of death, results confirmed by using the pilot sample. Cancer had mixed effects when comparing the results using the final (negative) and the pilot (positive) samples. Hospital admission and emergency-room visits had no significant effect on willingness to pay either, both results using final and pilot samples indicating a negative (but non significant) effect.

The only single relevant result regards the statistically significant effect of the physical function score (*pfs*) on the willingness to pay for a mortality risk reduction. This result has been consistently observed in all sub-samples both using the final and the pilot sample. The positive sign of the parameter suggests that the healthier the respondent feels (physically) the more this respondent would be prepared to pay for a reduction in the risk of dying.

6.3. Willingness-to-pay estimates for risk reductions happening in the future

The survey instrument proposed by Krupnick *et al.*, (1997,1999) includes the elicitation of the respondents' willingness to pay for a risk reduction happening in the future, when the respondent is aged 70. This question was posed to all respondents aged between 40 and 60 years. This information is important given the latency period related to some health diseases associated with air pollution such as cancer. The willingness to pay for a risk reduction happening in the future is expected to be lower than the willingness to pay for an immediate risk reduction of the same size since there are uncertainties about the future, related both to individuals surviving to the period when they would enjoy the benefit, and to the individuals' marginal utility of future consumption. This is theoretically demonstrated in models suggested by Cropper and Sussman (1990) and Alberini *et al.*, (2002b). The former model was discussed in the theoretical literature review.

6.3.1. Non-parametric and parametric results

Initially, the same procedure described in Chapter 5 and adopted to estimate willingness to pay for two different immediate risk reductions was used to estimate the willingness-to-pay values for a 5-in-1000-risk reduction that happens in the future. First, the non-parametric willingness to pay was estimated using the responses to the initial bid question (Annex 10.3 presents the results using the responses to both initial and the follow-up questions), followed by a parametric estimation using the constant-only bid function and the Weibull parametric model. The validity test was performed for the final sample and the pooled data as well.

Table 63: Non-parametric (lower-bound) Turnbull estimation of mean annual willingness to pay – risk reduction in the future (US$ 2003)

	5-in-1000 risk reduction over 10 years		
	Total sample	Without Flag0 =1	Without Flag4 =1
Starting at age 70	461.77	99.33[(a)]	493.66
Starting immediately	522.09	464.74	524.93

Estimates are distribution-free and conservative (lower bound). US$ 1 = R$ 3.40 during the survey period (March/2003).
(a) The low figure is due to lack of monotonicity of the empirical density function in the highest bids, i.e. the percentage of 'yes' responses did not decrease as bid values increased.

Table 63 shows the non-parametric willingness-to-pay estimates. A small reduction is observed in the lower-bound figures relating to the 5-in-1000 immediate and future risk reduction presented in Chapter 5 and re-introduced in Table 63. This suggests a preference for immediate consumption over future consumption of the same good, and indicates an implicit positive discount rate. However, this result is not confirmed when the parametric results are estimated (Table 65). The confidence intervals were calculated using the confidence interval of the estimated parameters (Table 64) of the constant-only regression model assuming the Weibull distribution.

Table 64: Weibull accelerated failure-time model – risk reduction in the future

	Total sample		Flag0 = 0		Flag4 = 0	
Regressors	Coefficient	Robust standard errors	Coefficient	Robust standard errors	Coefficient	Robust standard errors
	5-in-1000 future risk reduction					
Constant	7.62290(*)	0.10795	7.55288(*)	0.12746	7.67650(*)	0.11436
Ancillary parameter	0.80461	0.04208	0.79237	0.04906	0.80572	0.04377
Log likelihood	-266.02575		-198.73985		-236.58234	
N	154		114		137	
	Excluding 'yeah-saying' respondents					
Constant	6.65608(*)	0.12785	6.69794(*)	0.14000	6.64923(*)	0.13712
Ancillary parameter	086318	0.05985	0.87980	0.0693	0.86171	0.06556
Log likelihood	-74.918476		-66.192932		-65.005162	
N	53		46		46	

Notes: Flag0 = Inconsistent maximum willingness-to-pay responses for both immediate risk reductions.
Flag4 = Wrong answer to both probability tests.
(*) significant at 1%; (**) significant at 10%.

The parametric willingness to pay for a 5-in-1000 risk reduction that happens in the future is very similar to those estimates referring to the 5-in-1000 immediate risk reduction. In fact, with the exception of the sub-sample where the inconsistent responses were excluded (Flag0), the willingness-to-pay estimates for the risk reduction in the future are higher than those for an immediate risk reduction, suggesting negative discount rate[84]. This is an unexpected result since it is supposed that a developing country, presenting great inequality regarding income distribution, and a significant share of poor people should present a positive and relatively high social discount rate. The expected result, however, is observed when individuals who stated inconsistent willingness-to-pay responses are excluded from the analysis (Flag0), which suggests that inconsistent respondents did have an impact on the willingness-to-pay estimates for a risk reduction that happens in the future. More attention will be given to this specific sub-sample during the coming analyses in this section.

Table 65: Parametric estimation of mean and median annual willingness to pay (US$ 2003) – risk reduction in the future – Weibull distribution (95% CI)

	5-in-1000 risk reduction over 10 years *starting at age 70*		
	Total sample	Flag0	Flag4
Mean	678 (514 – 909)	639 (461 – 902)	715 (534 – 973)
Median	381 (322 – 448)	353 (289 – 428)	402 (336 – 478)
	5-in-1000 risk reduction over 10 years – *starting immediately*		
Mean	653 (528 – 817)	712 (549 – 936)	653 (519 – 833)
Median	383 (337 – 434)	404 (346 – 471)	376 (327 – 430)
	5-in-1000 risk reduction over 10 years – *starting immediately – age 40 to 60 years*		
Mean	619 (477 – 817)	687 (503 – 961)	637 (486 – 852)
Median	375 (322 – 436)	409 (339 – 489)	387 (329 – 454)

US$ 1 = R$ 3.40 during the survey period (March/2003).

One possible reason for the unexpected result shown in Table 65 – the parametric willingness to pay for a risk reduction in the future being higher than the willingness to pay for an immediate risk reduction of the same size – might have been the observed behaviour of part of the respondents in 'agreeing' with all proposed bid values. As already explained in Chapter 5, this 'cooperative behaviour' was a problem observed during the survey that might be related to the sampling and format of the interviews (paying individuals to attend the interview), which can be in part responsible for the high percentages of 'yes' responses for all bid values.

[84] The same result was observed when comparing the willingness-to-pay estimates for a risk-reduction in the future with the figures for an immediate risk reduction estimated for the same age group (40 to 60 years old individuals).

The mean and median willingness to pay is now estimated using a sub-sample where the 'yeah-say' respondents are excluded. The sample was reduced to 53 respondents and the sub-samples (Flag0 and Flag4) had 46 individuals only. Table 66 shows that the mean and median estimates obtained with the sample excluding 'yeah-say' respondents are in accordance with the expected results, that is, willingness to pay for a risk reduction in the future being smaller than for an immediate risk reduction.

Table 66: Mean and median annual willingness to pay (US$ 2003) – Weibull distribution (95% CI) – risk reduction in the future – without 'yeah-say' respondents

	5-in-1000 risk reduction over 10 years *starting at age 70*		
	Total sample	Flag0	Flag4
Mean	217 (163 – 292)	227 (166 – 316)	215 (159 – 297)
Median	166 (135 – 204)	172 (137 – 215)	165 (132 – 205)
	5-in-1000 risk reduction over 10 years – *starting immediately*		
Mean	244 (192 – 315)	254 (195 – 336)	247 (192 – 323)
Median	201 (168 – 239)	208 (171 – 251)	205 (170 – 246)

US$ 1 = R$ 3.40 during the survey period (March/2003).

The exercise presented above has the objective to highlight the impact of 'yeah-saying' behaviour on willingness-to-pay estimates in this study. It cannot be claimed that the sub-sample obtained when excluding the 'yeah-say' respondents can be considered any better than the original sample because some of the respondents may genuinely have accepted the bid-values offered to them. In other words, it is not possible to distinguish the true 'yes' response from the 'cooperative approach'.

6.3.2. Validity tests of willingness-to-pay estimates

The validity test of willingness-to-pay estimates (Table 67) included the same set of covariates considered in the validity tests of the willingness to pay for the immediate risk reductions (Chapter 5) plus the subjective measures of how likely the respondent would survive to age 70 (0 – 100%) and how the respondent consider that his or her health would be at the age of 75 compared with his or her actual health status (scale from 1 – much better – to 5 – much worse).

Table 67: Validity test - willingness-to-pay for a 5-in-1000 future risk reduction

Weibull model	Total sample		Flag 0		Flag 4	
Regressors	Coefficient	Robust standard errors	Coefficient	Robust standard errors	Coefficient	Robust standard errors
Constant	15.1731$^{(*)}$	5.20817	12.6340$^{(**)}$	7.64139	16.8361$^{(*)}$	5.41379
Gender	0.13015	0.12639	0.24243	0.19098	0.11919	0.14951
Age	-0.27402	0.20377	-0.22785	0.29941	-0.3949$^{(**)}$	0.21810
Age square	0.00262	0.00207	0.00227	0.00305	0.00404$^{(**)}$	0.00223
Years of education	-0.00505	0.01857	-0.00366	0.03001	0.00880	0.02154
Income (individual)	0.00062$^{(*)}$	0.00020	0.00052$^{(**)}$	0.00029	0.00063$^{(*)}$	0.00022
If respondent smokes	-0.20028	0.14844	-0.4318$^{(**)}$	0.25812	-0.3057$^{(**)}$	0.15978
Degree of faith in religion	-0.10816	0.07747	0.09954	0.11353	-0.04053	0.10576
Health insurance	-0.3439$^{(**)}$	0.14841	-0.23393	0.22055	-0.3877$^{(**)}$	0.15211
If respondent is married	0.33022$^{(**)}$	0.15371	0.47829$^{(**)}$	0.24544	0.55891$^{(*)}$	0.18580
Has children	0.10437	0.21120	0.33824	0.30361	0.09410	0.21876
Self-assessed comprehension of the concept of probabilities	0.00076	0.05413	0.11749	0.07943	0.02584	0.05877
If respondent considered his/her finances when stating WTP	0.19979	0.14853	0.34629	0.23201	0.13981	0.17163
Role limitation physical score	0.00103	0.00206	0.00430	0.00299	0.00347	0.00216
Energy vitality score	-0.00616	0.00393	-0.00580	0.00574	-0.00478	0.00421
Subjective expected age of death	-0.03476	0.03635	-0.1097$^{(**)}$	0.05872	-0.06872	0.04550
Subjective health status at age 75	-0.06846	0.06532	-0.2096$^{(**)}$	0.11952	-0.01788	0.07323
Subjective chances of surviving to age 75	0.00233	0.00202	0.00477	0.00366	0.00409	0.00274
Scale parameter (1/p)	0.758366		0.9322109		0.8438793	
N	154		114		137	
Log likelihood	-184.96289		-174.9646		-199.37907	

Notes: (*) significant at 1%; (**) significant at 10%.

As can be seen in Table 67, income is the most relevant determinant of willingness to pay for a risk reduction that takes place in the future, as it is for the immediate risk reduction. Respondents' marital status is now a relevant determinant of the willingness to pay for risk reductions in the future, the positive sign of the coefficient suggesting that married people are more concerned about their future and longevity. Health insurance is again an important factor to determine the willingness to pay, and the negative sign suggests that those individuals with no health insurance tend to pay more for a risk reduction in the future. Other covariates were significant but not consistent among the different sub-samples. For example, the subjective possible age of death was significant when the sub-samples excluding inconsistent responses and individuals who gave wrong answers to the probability tests were used. The negative sign of the coefficient suggests that the longer the respondent expected to live, the lower this respondent would like to pay to reduce his or her probability of death in the future.

The expected age of death is possibly correlated with the other two variables indicating subjective future expectations, and this fact may have lowered the significance of these other covariates. This is confirmed by the fact that the only sub-sample where the expected age of death is not significant had the subjective chances of surviving to age 70 significant.

Table 68: Validity test - willingness-to-pay for a 5-in-1000 future risk reduction (Pooled data)

Weibull model	Total sample		Flag 0		Flag 4	
Regressors	Coefficient	Robust standard errors	Coefficient	Robust standard errors	Coefficient	Robust standard errors
Constant	7.06575	4.88111	4.00525	6.21500	5.82631	5.17680
Gender	0.03365	0.13095	0.13879	0.15883	0.04238	0.13974
Age	0.03210	0.19862	0.12862	0.24985	0.08334	0.21161
Age square	-0.00037	0.00200	-0.00124	0.00251	-0.00083	0.00213
Years of education	0.02674	0.01805	0.04899(**)	0.02409	0.03086	0.01903
Income (individual)	0.00044(*)	0.00005	0.00041(*)	0.00005	0.00042(*)	0.00005
If respondent smokes	-0.08933	0.15183	-0.11438	0.17738	-0.13635	0.17089
Degree of faith in religion	-0.1687(**)	0.07767	-0.1898(**)	0.10002	-0.2260(**)	0.08829
Health insurance	-0.52609(*)	0.14025	-0.3706(**)	0.19421	-0.56132(*)	0.15379
If respondent is married	0.11269	0.15436	0.09629	0.19628	0.28158(**)	0.17148
Has children	0.16758	0.21315	0.16278	0.26657	0.26603	0.22384
Self-assessed comprehension of the concept of probabilities	0.00783	0.06457	0.05528	0.09163	-0.006340	0.06887
If respondent considered his/her finances when stating WTP	0.28720(**)	0.14507	0.32392(**)	0.18545	0.22172	0.15132
Role limitation physical score	0.00047	0.00220	0.00041	0.00287	0.00081	0.00244
Energy vitality score	0.00031	0.00451	0.00183	0.00551	0.00078	0.00486
Subjective expected age of death	-0.00627	0.03419	-0.03232	0.04485	-0.02154	0.03823
Subjective health status at age 75	-0.10188	0.08632	-0.11955	0.11403	-0.10942	0.09324
Subjective chances of surviving to age 75	0.00286	0.00255	0.00078	0.00332	0.00270	0.00283
Scale parameter (1/p)	1.311171		1.361024		1.328394	
N	342		272		314	
Log likelihood	-643.93139		-520.69366		-595.40321	

Notes: (*) significant at 1%; (**) significant at 10%.

When the pooled data are used for the validity test in order to confirm or not the determinants of willingness-to-pay responses (Table 68), a similar result obtained for immediate risk reduction is also observed for the risk reduction in the future. Income is still the most significant determinant of willingness-to-pay responses, with health insurance and religion being other important determinants that are consistent across the sub-samples. Financial constraint and education have now an important role in some sub-samples, seeming to be the influence of the more educated individuals in the pilot sample. From the results of the validity tests it can be concluded that the willingness-to-pay responses are robust in regard to different samples, that is, the same significant factors (education and health insurance) are consistent across different samples, with education, religion and marital status demonstrating importance in different sub-samples.

6.4. Summary and comparison of results

A final research question in this study regards the identification of possible differences in attitudes and preferences towards mortality risks between a developing country (Brazil) and developed countries, where the number of studies aiming to estimate the value of a statistical life is significantly larger than in the developing world. In other to facilitate the comparison of results and the attempt to identify possible cultural and attitudinal differences between the populations of Brazil and other developed countries the focus of the comparative analysis is on the studies that used the same methodology and survey instrument as this study in Brazil. The rationale for limiting the analysis to those studies is that by doing so potential differences in results due to differences in the studies' design – the valuation method, survey design and statistical methods used – can be eliminated.

For example, it is difficult to compare the value of a statistical life estimates generated in revealed preference methods such as the 'compensating-wages' studies with the results of stated preference methods such as the contingent valuation. As shown in the empirical literature review, the willingness-to-pay and value of a statistical life estimates can be very sensitive to the method and data used in the valuation exercise. In addition, there are different designs of contingent valuation surveys that may affect the produced estimates. For example, a contingent valuation study using an open-ended willingness-to-pay question may present results significantly different from a similar contingent valuation study using the dichotomous choice format (e.g. McFadden, 1994). Thus, eventual differences in results can be more directly attributed to observed differences between the samples if those results are generated under the same methodology, set of assumptions and statistical models. Also, if the samples are assumed as representative of the respective populations then differences in results can be considered as reflecting different attitudes towards risk.

This section discusses potential cultural and/or attitudinal differences between developed and developing countries in regard to the valuation of small risk reductions in the probability of death. The studies undertaken in the US, Canada, the UK, France and Italy are compared with the Brazilian study in terms of sample characteristics and main results. The studies undertaken in Chile, Japan and China were not considered given the small sample size observed in the Chilean and Japanese studies (actually pilot surveys) and the different age group observed in the Chinese study – 95% of respondents were younger than 45 years old. It starts with a comparison of the samples used in the selected studies (Table 69).

Table 69: Comparison of mortality valuation studies – sample characteristics

Sample characteristics	US	Canada	UK	France	Italy	*Brazil*
Sample size	1200	930	330	299	292	283
Age	54.4	54.2	58.0	55.3	57.0	56
Male	47%	46%	49%	47%	48%	45%
Years of education	13	13.7	14.1	11.0	12.9	7.6
Income	($ 2000)	($ 2000)	($ 2002)	($ 2002)	($ 2002)	($ 2003)
Mean	53,000	46,800	43,677	35,061	43,698	2,982
Median	55,000	50,000	42,146	34,872	27,233	2,647
Married	72%	NA	82%	65.5%	NA	65%
Baseline risk of dying	187	123	199	109	50	220
Has health insurance	6%	69%	34%	89.9%	NA	43.8%
Heart disease	21%	9.6%	8%	12%	12%	23%
High blood pressure	NA	20.2%	28%	21%	21%	34.6%
Cancer	11%	3.4%	6%	6%	7%	9.5%
Asthma	10%	10.3%	13.6%	10.4%	NA	16.2%
Bronchitis, emphysema or chronic cough	16%	14.0%	15.4%	14.4%	12.7%	

As can be seen in Table 69, the samples used in the analysis are very similar in terms of their composition, especially regarding mean age of respondents and gender shares. The North American samples are three to four times bigger than the samples used in the European countries and Brazil, although none of the samples can be claimed to be fully representative of the respective population. The most significant difference between the Brazilian sample and other samples regards the income and education levels of individuals. The median annual income in the Brazilian sample corresponded to one-tenth of the Italian median income and one-twentieth of the US income. Also, the average number of years in school in the Brazilian sample was four years smaller than the French sample and roughly half of the observed in the UK. The health status of individuals in the Brazilian sample was very similar to the US respondents, both presenting higher figures than in the other developed countries. These higher figures correspond to individuals with a hystory of heart disease, cancer and respiratory diseases. The percentage of respondents with high blood pressure is higher in the Brazilian sample than in any other country. It can be concluded that most of the differences observed in the willingness-to-pay results can be attributed to differences in preferences among Brazilian respondents, which can be related to differences in socio-economic characteristics, mainly income and education.

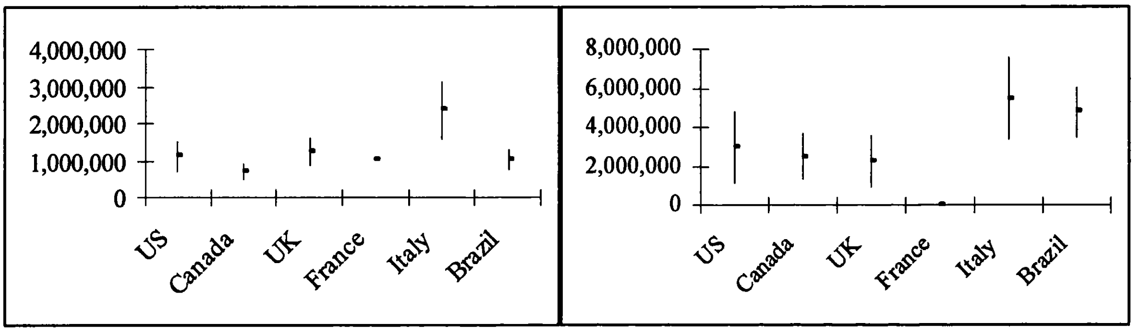
Table 70: Comparison of mortality valuation studies – main results

Results	US ($ 2000)	Canada ($ 2000)	UK ($ 2002)	France ($ 2002)	Italy ($ 2002)	*Brazil* ($ 2003)
WTP (1-in-1000 now) Mean Median	 483 111	 370 131	 360 96	 --- ---	 760 336	 610 (241) 346 (197)
WTP (5-in-1000 now) Mean Median	 770 350	 466 253	 802 422	 --- 522	 1,577 788	 653 (245) 384 (208)
WTP (5-in-1000 future) Mean Median	 727 385	 265 55	 256 100	 650 254	 453 177	 639 (217) 353 (166)
VSL (5-in-1000 now) Mean Median	 1,540,000 700,00	 933,000 506.000	 1,604,000 844,000	 --- 1,043,573	 3,154,000 1,576,000	 1,306,941 (489,752) 767,187 (415,831)
VSL (1-in-1000 now) Mean Median	 4,830,000 1,110,000	 3,704,000 1,312,000	 3,600,000 960,000	 --- ---	 7,600,000 3,360,000	 6,099,858 (2,412,626) 3,458,245 (1,971,617)
Determinants of WTP/VSL	Income, gender, race	Income, mental health, if can afford payment	Income, education	Income	Income	Income, health insurance, physical sc, religion
Impact of age	No effect	Negative after 70	No effect	No effect	Negative after 70	No effect
Impact of health status	Positive for high blood pressure	No effect	Positive for ER visit or hospitalisation			Positive for physical health score

Note: Figures obtained when excluding 'yeah-saying' respondents are in parenthesis.

Table 70 shows the comparison of the main results of the selected studies. The willingness-to-pay and value of a statistical life estimates in Brazil are as high as those observed in developed countries – and in some cases higher. For example, the willingness to pay for a 1-in-1000 risk reduction in Brazil was almost twice the same estimate for Canada and the UK (mean values) and almost three times bigger when the median values are considered. The figures (mean and median) corresponding to the 5-in-1000 contemporaneous risk reduction – the first willingness-to-pay question posed in the Brazilian study – are similar to those observed in the US and the UK, higher than those observed in Canada but less than half of the Italian estimates. This result is difficult to justify via differences in income and education levels since the figures do not observe any proportionality in regard to income differentials[85]. Interestingly, income is the most influential variable in all validity tests of willingness-to-pay responses in all studies, which suggests that income differences between countries should be reflected in willingness-to-pay estimates.

Figure 4: Comparison of VSL estimates using 5-in-1000 and 1-in-1000 immediate risk reductions



The best explanation for the relatively high estimates found in the Brazilian study relies on the 'cooperative' behaviour identified among the Brazilian respondents. The 'yeah-saying' behaviour, identified in other contingent valuation studies (e.g. Ready *et al.*, 1986), seems to have had a significant impact on the willingness-to-pay estimates, and consequently, the value of a statistical life in Brazil. As shown in Chapter 5 and Table 46, when supposed 'yeah-saying' respondents are excluded from the analysis, the willingness-to-pay results are much smaller, implying value of a statistical life US$489.752 (mean) and US$415.831 (median) for a 5-in-1000 immediate risk reduction. The mean estimate, for example, corresponds to approximately half the estimate for Canada, one-fifth of the US and the UK figures, and almost one-sixth of the Italian result. The same is observed regarding the value of a statistical life in Brazil using the median willingness-to-pay estimate. The results obtained when excluding potential 'yeah-saying' respondents do not follow strict proportionality to income differentials between the countries[86], a result that was pointed out by Chesnut *et al.*,

[85] In addition, no cultural differences could have been observed during the initial phases of the research and using the debriefing questions available in the questionnaire.
[86] Income elasticity of willingness-to-pay estimates are shown in Chapter 5. Income elasticity of the value of a statistical life using the 5-in-1000 risk reduction mean values were estimated as

(1997). General health is seen as a basic necessity and those with lower incomes may be willing to pay a higher share of their income to protect their health. However, as explained before, the sub-sample excluding 'yeah-saying' respondents cannot be claimed as producing more reliable estimates than the full sample since it is not possible to distinguish true 'yes' responses (obtained in a utility maximising process constrained by income) from the 'yeah-saying' responses.

Regarding the impact of age and health status on the willingness-to-pay responses, the Brazilian results suggest no significant effect of age. The absence of an age effect in the Brazilian study was similar to the US, France and UK results, whilst the positive health status effect on willingness to pay was similar to the US and European studies, although for different health aspects.

6.5. Conclusions

This chapter investigated the impact that age and respondents' health status had on the willingness to pay responses. In addition, the mean and median willingness to pay for a risk reduction in the future was estimated, and a comparative analysis of results was undertaken with studies carried out in developed countries using the same methodology as the one used in this study.

There was no age effect on the willingness to pay for small risk reductions in Brazil in the samples and sub-samples available. The coefficients of the age variable in different models explaining the willingness-to-pay responses were always not significant. Mean and median willingness to pay for different age groups were estimated using the constant-only approach, and presented no consistent pattern between samples and sub-samples, which reinforces the conclusion that no significant age effect could be identified.

No cancer, respiratory or cardiovascular disease effect on willingness-to-pay responses could be spotted in this study, given the lack of statistical significance of the coefficients in the regressions. However, when relaxing for a moment the statistical significance of the parameters, the signs of the coefficients in regressions using the final sample suggest that the occurrence of respiratory (cardiac) diseases reduces (increases) the willingness to pay for a reduction in the probability of death, a result confirmed by

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$\eta = \dfrac{\%change VSL}{\%\text{change mean income}}$. The results suggest an income elasticity of VSL equal to 0.72 (US); 0.51 (Canada); 0.74 (UK), 0.91 (Italy), and 0.76 (France – median values).

using the pilot sample. Cancer had mixed effects when comparing the results using the final (negative) and the pilot (positive) samples. Hospital admission and emergency-room visit had no significant effect on willingness to pay, both results using final and pilot samples indicating a negative (but non significant) effect. A relevant result regards the statistically significant effect of the physical function score on the willingness to pay for a mortality risk reduction; a consistent result observed in all sub-samples both using the final and the pilot sample. The positive sign of the parameter suggests that the healthier the respondent feels (physically) the more this respondent would like to pay for a reduction in his or her risk of dying.

Willingness-to-pay estimates for a reduction in risk of dying in the future were not consistent with theory when the total sample and one sub-sample (Flag4) were used. However, when individuals who inconsistently answered the willingness-to-pay question were removed from the sample the results were in accordance with theory. It has been shown that the 'cooperative behaviour' demonstrated by a significant share of respondents had an impact on the willingness to pay for a risk reduction in the future. When the 'yeah-say' respondents were removed from the sample the results were all in accordance with the theory.

7. Policy analysis

As can be seen in the previous chapters, the estimation of the value of a statistical life and the value of a statistical life year involves a number of uncertainties, both methodological and empirical. The willingness-to-pay-based measures can be estimated using revealed preference methods such as the 'compensating-wage', the hedonic price and averting behaviour methods; or stated preference methods, for example, the contingent valuation. Each method has specific advantages and disadvantages that are reflected in form of uncertainties about the resulting value of a statistical life (year) estimates. As shown in the empirical literature review, the estimates can vary substantially, depending on a number of characteristics of the studies.

This Chapter aims to discuss the relevance of the empirical results obtained in this study in terms of policy analysis in Brazil. It starts, in section 7.1, with a discussion of alternative approaches that can provide non-willingness-to-pay measures of the value of a statistical life (year), and their usefulness for establishing parameters for comparison of the results presented in this study. In addition, the Brazilian studies available are reviewed and the proxies for the value of a statistical life in Brazil are compared with the estimates presented in this study. Section 7.2 discusses the benefit transfer procedures that are, in general, the procedure adopted in developing countries in the absence of original revealed and/or stated preference studies. Some benefit transfer validity tests are performed to estimate potential 'errors' of benefit transfer estimates when compared with willingness-to-pay estimates generated in this study. Finally, section 7.3 presents previous studies undertaken in Brazil and explores the implications for policy analysis of using benefit transfer estimates or the results provided in this study.

7.1. The value of a statistical life implicit in life-saving interventions in Brazil

Although the willingness-to-pay approach is perhaps the most suitable method for estimating the value of mortality risk reductions, it is useful to compare these willingness-to-pay-based estimates with other estimates derived from different life-saving interventions in Brazil. The rationale for this comparison is that other approaches may generate approximate values that can be regarded as boundaries for the true value of a statistical life (year), and help reducing the uncertainties when using such estimates for policymaking. For example, Rabl (2004) considers it relevant to investigate the value of a statistical life (or life year) implicit in life-saving public decisions because consistency requires using the same value for all mortality risks that involve the same attributes, such as involuntariness and amount of suffering. In other words, "if people face continuous safety choices in a variety of contexts, the same individual should exhibit the same risk-money trade-off across different contexts, provided the character of the risks is the same" (Viscusi and Aldy, 2003). In this circumstance, it is possible to analyse data on actual expenditures for risk reductions in different sectors in the economy and estimate the implicit value of a statistical life. Finally, Ramsberg and Sjoberg (1997) argues that an implied value of a statistical life is simply the cost-effectiveness of a life-saving intervention, measured as cost per life saved.

Different types of life-saving interventions can be used for the purpose of investigating the cost per statistical life saved. These interventions can be grouped as medical or health-related interventions or non-medical interventions. The former group includes clinical tests aiming to screen for the presence of specific diseases and the effectiveness of medical interventions for the treatment of these diseases (e.g. cancer, heart disease), and public health (large scale) interventions such as influenza vaccination, malaria control, and AIDS prevention programmes. Non-medical life-saving interventions can include activities aiming to reduce risks of fatal accidents in the transport sector (e.g. regulation on seat belts, helmet use; road improvements); risk mitigating measures in the energy supply chain (e.g. emission control in coal-fired power plants, radiation control in nuclear power plants); occupational interventions such as toxin control in the working environment (e.g. benzene exposure control, asbestos ban in certain products); measures for reducing risks of fatal residential accidents (e.g. use of smoke detectors; compliance with safety standards in construction); and environment-related interventions such as air and water pollution control (e.g. emission control from mobile sources, pesticide use control).

The cost-effectiveness literature can provide some evidence of the costs per life saved and/or cost per year of life saved. In general terms, cost-effectiveness analysis describes an intervention or measure in terms of incremental costs per unit of incremental benefit, such as health effects (Garber and Phelps, 1997). It aims to promote economic efficiency in the allocation of resources by identifying those alternatives that costs less to achieve one unit of a given benefit. Some authors (e.g. Krupnick, 2004) consider the cost-effectiveness analysis a particular form of cost-benefit analysis, where the benefits are not monetised but rather, expressed in terms of a non-monetised unit. Net cost-effectiveness analysis is a particular type of cost-effectiveness analysis where a part of the benefits is monetised and included in the numerator of the cost-effectiveness ratio (CER)[87] – costs minus monetised benefits divided by non-monetised benefits (Krupnick, 2004).

Cost-effectiveness studies in general use two different metrics to express the benefits of alternative interventions or measures – physical effects or health indices. The former metric, physical effects, involves expressing the benefits of interventions in terms of lives saved, life-years saved or life expectancy variations. In general, it is the simplest way to estimate the cost-effectiveness ratio since most epidemiologic studies already present outcomes in terms of physical effects. However, the disadvantage of using the physical effect metric is that only one effectiveness measure can be assessed. For instance, when morbidity effects represent an important role in total physical effects the analysis using only one health effect – mortality – can be misleading (Krupnick, 2004). An alternative metric used in cost-effectiveness analysis, very popular in the medical literature, is given in terms of health indices, such as the quality-adjusted life years (QALY), which has already been discussed in the empirical literature review. Health indices are calculated by weighting the amount of time an individual will spend in each future health state by an index or score that measures the health-related quality of life in that state, which allows the analyst to combine morbidity and mortality effects in the same analysis. This type of analysis is often found in the medical literature to compare the cost-effectiveness of different types of treatments or medical interventions, given that the use of new medicines, therapies or treatments should include economic justification in addition to clinical efficacy.

Two pertinent questions can be posed if cost-effectiveness estimates are to be compared to the Brazilian value of a statistical life and value of a statistical life-year: (i) how are cost-effective measures comparable with willingness-to-pay-based measures? (ii) Is cost-effectiveness a sound approach from an economic perspective? Regarding the first question, it seems that the comparability of measures is possible when cost-effectiveness ratios are estimated in studies with a number of desired characteristics. For

[87] CER is the ratio of the incremental cost relative to incremental benefit associated with competing measures.

example, "when effectiveness is measured in terms of life expectancy, the optimal[88] cost-effectiveness ratio represents the same concept as the (marginal) willingness to pay – the amount an individual would pay to reduce a risk of death" (Graber and Phelps, 1997). That is, when cost-effectiveness is conducted in a societal perspective, accounting for all costs of the measure – direct and indirect[89] – and benefits are measured in terms of life expectancy, the cost-effectiveness ratio represents the upper limit of what society is willing to pay for an additional unit of benefit. Another desirable characteristic refers to the alternatives under analysis in cost-effectiveness studies. In the medical literature most studies compare a new intervention to the current practice or the established intervention to deal with the disease, which may not represent the total benefit of the new intervention. For a complete economic value estimate new interventions should be compared with the no-intervention alternative.

On the other hand, Kuchler and Golan (1999) examined different approaches that economists and health policy analysts have developed to evaluate policies affecting health and safety, including the willingness-to-pay approach and cost-effectiveness analysis. The authors concluded that these approaches are not comparable on the basis that cost-effectiveness analysis measures costs in terms of ex-post damages while the willingness-to-pay approach measures costs in terms of ex-ante risk perception. In other words, "willingness to pay reflects expectations rather than realised damages" (Kuchler and Golan, 1999). Ramsberg and Sjoberg (1997) noted that although an implied value of life is the cost-effectiveness of a life-saving intervention, this latter estimate is an implied value of a statistical life only under the following conditions: (i) the intervention is implemented; (ii) the unique purpose of the intervention is life-saving; and (iii) the intervention can be continuously implemented up to infinity[90].

Regarding the second question, whether cost-effectiveness is a sound approach from an economic perspective, Garber and Phelps (1997) used a Neumann-Morgenstern (expected) utility framework to show how a cost-effectiveness criterion can be derived to guide resource allocation decisions regarding medical interventions. It was intended

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[88] A cost-effectiveness ratio is optimal when it equals the sum of future individuals' expected utility normalised by the marginal utility of income at the present.
[89] Cost-effectiveness ratios often include only resource costs (direct medical and non-medical costs) but lack some measure of the opportunity and disutility costs (e.g. lost productivity, dread and suffering before death).
[90] For example, reducing or eliminating lead from gasoline is an intervention that once implemented it is possibly maintained forever (continuously to infinity). This type of intervention tends to be more expensive and generate higher cost-effectiveness ratios than non-continuous or temporary interventions such as campaigns against smoking.

to establish some foundations for cost-effectiveness analysis based on economic theory, and to provide some theoretical justification for the cost-effectiveness technique use. The authors assumed that cost-effectiveness analysis is applied to maximise an aggregate of individual utilities with similar health prospects and preferences. The conclusions were that when applied to a heterogeneous population level (groups of people whose preferences or health status vary greatly) the cost-effectiveness criterion is unlikely to yield Pareto-optimal resource allocations. Also, that cost-effectiveness is internally consistent for selecting health interventions, that is, the optimal cost-effectiveness cut-off point[91] is the same for all interventions, regardless of when (present or future) the interventions exert their effects. However, these conclusions hold only within the framework of standard Von Neumann-Morgenstern utility maximisation, which includes some restrictive assumptions such as additive separability, risk neutrality over lifetime, and constant rate of time preference.

The limitations of cost-effectiveness analysis include the fact that it cannot measure variations in social welfare and that it does not take into account social concerns, such as priority for the sick, reducing social inequalities in health, or wellbeing of future generations (Murray *et al.*, 2000). In addition, it measures only one impact, which means that it is not appropriate to evaluate interventions in areas that involve significant other impacts simultaneously. Also, cost-effectiveness results are in general context-specific and cannot be used to inform policy debate in another population (transferability). Other issues in cost-effectiveness analysis include discounting – costs are incurred over a period of time and have to be converted into a present value – which poses a problem to the analyst regarding which discount rate to use. In general, sensitivity analysis is performed to account for uncertainties regarding the social discount rate chosen.

In summary, most cost-effectiveness analyses compare treatments or measures related to the common practice to deal with the disease, intending to assess the benefits of new techniques in contrast to established usual treatments. However, the economic measure that would represent the total benefit of the new technique would be obtained by assessing the incremental benefit when compared to the 'no-treatment' alternative (Murray *et al.*, 2000). In other words, "...inferring the cost-effectiveness ratios of common practices provides little guidance regarding the optimal cost-effectiveness ratio

[91] Cut-off point is the assumed willingness to pay for an additional unit of benefit (Murray *et al.*, 2000).

– that is, the willingness to pay for a health effect" (Garber and Phelps, 1997). This fact has to be kept in mind when comparing the value of a statistical life and the value of a statistical life year estimated in this study with those costs per life saved obtained in the cost-effectiveness literature. Cost-effectiveness ratios when obtained comparing alternative medical treatments can be regarded as lower bound estimates of those figures presented in this study, which are based on the willingness-to-pay approach.

7.1.1. Health-related (medical) interventions

Cost-effectiveness studies of medical interventions in Brazil that used the physical effect metric – the one of interest for the purposes of this study – are not many. These studies, both clinical and public health programmes were investigated in specialised medical databases, such as the PubMed. The paucity of references obtained in these databases confirms that this type of analysis is not common in Brazil, resulting in only four studies being identified: Akhavan *et al.* (1999) on the cost-effectiveness of a public health programme (malaria control) undertaken in the Brazilian Amazon region; a cost-effectiveness analysis comparing four treatments of end-stage renal disease in Brazil (Sesso *et al.*, 1990); and the results of a clinical experiment involving the effectiveness of alternative methods for controlling heart disease (Vieira *et al.*, 2001). Another identified cost-effectiveness study in Brazil was not obtained (Akhavan, 2000) and could not be included in this section. This study presented a cost-effectiveness analysis of Chagas disease control in Brazil.

- Health programme (Malaria control)

Akhavan *et al.* (1999) presented results of a cost-effectiveness analysis of a malaria control programme (PCMAN) undertook in the Brazilian Amazon basin between 1989 and 1996. The malaria control programme arguably produced health benefits partly by preventing new cases of malaria (vector control), some of which would have ended in death, and by treating existing cases, particularly by preventing deaths from *P.falciparum*[92] infection.

The authors estimated the health benefits from vector control by obtaining the projected incidence of cases of malaria and the expected severity (share of *falciparum* in

[92] *Plasmodium falciparum* – mosquitoes most likely to transmit malaria, which causes nearly all deaths in the Brazilian Amazon basin. Other malarial parasite is known as *Plasmodium Vivax*, but unlike *Plasmodium falciparum* is rarely fatal.

total cases) and lethality (case fatality rate) to derive the losses in deaths that would have occurred in the absence of the programme. For the period 1989-1996 a coefficient of incidence growth of malaria (new cases per 100,000 population) was assumed to be equal to the coefficient observed between 1980 and 1988, resulting in predicted 5.5% of the population suffering an attack of malaria per year. The number of prevented cases of malaria due to the control programme was estimated by applying the difference between observed and predicted incidence to the population of the Amazon basin. The observed severity, or share of malaria cases due to *falciparum*, was between 53-55% from 1984 to 1987. Furthermore, in the absence of the control programme severity it was assumed that it would remain at that level between 1989 and 1996. Finally, it was assumed that 10% of those sick with *falciparum* die within a short period of time if not treated, which is a conservative assumption, the authors argue, based on expert consultations. The average age at death from malaria during the period of analysis was 14 years, age at which life expectancy was 66 years. The future was discounted at a constant annual rate of 3% to estimate the number of discounted years lost to premature mortality. The total number of years of life lost per fatal case of malaria after age weighting and discounting was estimated to equal to 36.27 years/life lost and the total number of deaths avoided by preventing new cases of malaria amounted to 100,687.

Akhavan *et al.* (1999) also estimated the gains from treating observed cases during 1989-1996, arguably a simpler estimation given that only the observed incidence and severity matter. Lethality without treatment was assumed 10%, while lethality with treatment declined from 0.72% to 0.40% between 1980 and 1988. It was observed that overall mortality statistics are substantially under-reported: some people die without getting treatment and some die even after receiving ambulatory treatment, and these deaths may not be registered. To compensate the under-reported statistics, the authors assumed that on average throughout the period, 0.78% of treated *falciparum* cases would have died. Lives saved by treatment were the number of people sick with *falciparum*, discounted to present value, times the difference between untreated and treated lethality. The total number of lives saved by malaria treatment under the control programme was estimated to equal 129,897.

The estimated costs of prevention and treatment were initially reported in Brazilian currency, converted to US dollars in the current year using the average of the official buying and selling rates for the dollar in that year, adjusted to 1996 US$ by the US GDP deflator for the current year, and discounted to 1996 present value at 3% per year. This procedure expressed all values in constant US dollars of 1996 purchasing power. The costs of prevention or vector control included capital investment and non-salary recurrent expenditures (e.g. insecticides, travel costs), plus working costs estimated from the number and type of personnel needed for vector control operations and salaries for each level of worker. The costs of treatment included the hospitalisation costs, ambulatory care and costs of diagnosis. The overall cost-effectiveness of saving lives under the malaria control programme ranged between US$ 2,492 and US$ 2,672 per life saved. Table 71 summarises the results.

Table 71: Cost-effectiveness of saving lives from malaria in Brazil– 1989-1996 (US$ 1996)

Concept	Prevention	Treatment	Total
Based on total cost	5,220	697	2,672
Based on net cost	4,808	697	2,492

Source: Adapted from Akhavan *et al.* (1999).

The estimates of cost per life saved by the malaria control programme in the Amazon basin seem to be very low when compared to other estimates of similar programmes elsewhere, according to the authors. They argue that previous estimates have been made mostly in Africa and Asia and have shown a wide range of costs per disability-adjusted life-year (DALY), which depend strongly on the case-fatality rate in each country. The cost estimation performed by Akhavan *et al.* (1999) considered only direct medical costs associated with the intervention, ignoring direct non-medical costs such as loss of productivity of those affected by malaria, as well as indirect costs related to the disutility of pain and suffering. It may be the main reason why the cost per statistical life saved estimated in this study is much lower than the willingness-to-pay based estimates shown is Chapter 5. Another characteristic of this cost-effectiveness analysis, that life saving was not the unique purpose of the malaria control programme, reinforces the inappropriateness of its results in terms of comparison with willingness-to-pay estimates.

- Clinical trial (Statins to control cholesterol)

Vieira *et al.* (2001) conducted a cost exercise of the use of statins, a drug used to lower cholesterol levels that, consequently, reduces the incidence of ischemic heart disease and its mortality effects. The study aimed to call attention to the need of carrying out a nationwide cost-effectiveness study concerning the use of statins in primary and secondary heart disease prevention[93] in Brazil. The authors argued that, given the high costs of the drug, the socio-economic situation in Brazil sometimes prevents the correct use of statins, even when the cardiologists are absolutely sure about its indication.

The authors performed a cost analysis of these drugs in Brazil, in relation to the benefits statins bring, based on international randomised clinical trials of primary and secondary prevention. Specifically, results (benefits) were used from studies on primary prevention: 'West of Scotland Coronary Prevention Study' (WOSCOPS) and 'Air Force/Texas Coronary Arteriosclerosis Prevention Study' (AFCAPS/TexCAPS); and secondary prevention: 'Scandinavian Simvastatin Survival Study' (4S), 'Cholesterol and Recurrent Events Trial' (CARE), and 'Long-term Intervention with Pravastatin in Ischaemic Disease Study' (LIPID).

The procedure adopted in the descriptive cost analysis was as follows: reported benefits of statins use in the WOSCOPS study show that the absolute reduction of total mortality was 0.9% in five years, that is, given the number of patients in the study, it corresponds to an absolute reduction of two deaths per one thousand treated patients per year, corresponding to 556 patients that would need to be treated during one year to prevent one death. According to the observed costs of this specific intervention (40mg of pravastatin/day) in the Brazilian market (cheapest commercial product available), one prevented death would cost about US$351,832. According to the results of the same study, one prevented death from a coronary artery disease would cost about US$633,508, while to prevent one death from any cardiovascular cause would cost US$452,356. The same procedure was undertaken for all international clinical studies. Table 72 summarises the findings.

Vieira *et al.* (2001) highlighted that the drug doses used to obtain the benefits reported in the different studies were considerably higher than those that are usual in Brazil for routine care. However, from the perspective of an evidence-based medical practice, the same reported doses should be used to obtain the same health benefits. Also, the authors define their cost-effectiveness analysis as partial because it considered only the evaluation of the drug costs, as compared with the prevented outcomes. "A complete cost-effectiveness analysis should encompass the entire amount of expenses, including the increase in medical visits and laboratory tests required by the treatment,

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[93] Primary prevention refers to patients with no history of heart disease; secondary prevention refers to patients that already have had an occurrence of a heart disease.

along with the decrease in hospitalisation and procedure expenses associated with the benefits of the treatment...only a complete Brazilian cost-effectiveness study could help us evaluate, from which risk level for coronary artery disease does the treatment with statins become cost-effective within our reality" (Vieira *et al.*, 2001).

Table 72: Costs per prevented death in Brazil (US$ 2000)

Study	Total mortality	Death from coronary artery disease	Death from cardiovascular cause	Death from coronary artery disease or acute myocardial infarct
WOSCOPS	351,832	633,508	452,356	---
AFCAPS/TexCAPS	---	1,694,241	1,270,681	---
4S	78,534	---	---	---
CARE	405,236	287,958	---	---
LIPID	124,607	203,665	---	107,330

Source: Adapted from Vieira *et al.* (2001).

In terms of comparability of results with willingness-to-pay estimates, this study has a number of positive characteristics. The medical intervention has the unique purpose of reducing the probability of death by heart diseases; the intervention can be continuously implemented (Ramsberg and Sjoberg, 1997); and it has benefits measured in physical effects (number of deaths), although there is no reference to the remaining years of life saved. The most important limitation of this study refers to the use of clinical results obtained in European populations, which are likely to present different health-related characteristics when compared to the Brazilian population. That is, the effect of drugs on the Brazilian population may differ from the effects observed in European countries due to differences in physical characteristics, health background, or even environmental characteristics such as air pollution concentration.

- Clinical trial (renal disease treatments)

Sesso *et al.* (1990) performed a cost-effectiveness analysis comparing four treatments of end-stage renal disease in Brazil and provided different estimates of costs per year of life saved. The authors investigated the following treatments: continuous ambulatory peritoneal dialysis (CAPD), in-centre haemodialysis (HD), cadaver donor transplantation (CD-Tx), and living related donor transplantation (LR-Tx). They used 121 records of patients (between 15 and 50 years old) who initiated treatment for end-stage renal disease in a large care centre in Sao Paulo from September 1983 to December 1985. All patients included in this cost-effectiveness study were clear of diabetes, chronic pulmonary disease, cardiovascular disease, liver disease, and chronic infection.

The measure of effectiveness used was the physical impact – life years of survival. In order to estimate the patient survival, the date on which the specific treatment started was defined as the beginning of the time period, and the end of the period of analysis (end of the follow-up period) was end of December, if the patient was alive. In case of death during the treatment, the date of death was the end of the time period relevant for estimating the surviving period. The number of years of survival was calculated by dividing the number of months of survival in the cohort by 12 and 24. The authors claim that determining costs and outcomes after one and two years was necessary because of the high initial costs of some services during the first year of treatment, for some treatments (e.g. transplantation surgery).

Sesso *et al.*, (1990) estimated immediate direct costs and induced indirect costs incurred by the Brazilian National Institute for Medical Assistance (INAMPS) to provide the treatments involved in the end-stage renal disease treatment programme. Direct costs included labour costs, the purchase of equipments and supplies, transplant and surgery fees, physician and hospital fees, and medications. Indirect costs were considered those costs borne as a consequence of the treatment instituted, its side effects. For example, costs induced by rejection episodes in case of transplants. There was no attempt to measure indirect non-medical costs such as lost earnings from decreased productivity. Table 73 shows the estimates of costs per life (year) saved that can be expected for each initial treatment strategy.

Table 73: Costs per life saved with end-stage renal disease treatments in Brazil (US$ 1985)

Renal disease treatment	CAPD	HD	CD-Tx	LR-Tx
Number of patients	21	47	10	33
Total costs	527,814	911,913	143,040	196,112
Cost per life year saved	12,134	10,065	6,978	3,022
Cost per life saved [(a)]	25,134	19,402	14,304	5,943

(a) Total costs divided by the number of patients alive at the end of the two-years programme.
Source: Adapted from Sesso *et al.* (1990).

The cost-effectiveness study undertaken by Sesso *et al.*, (1990) produced costs per life (year) saved per specific medical treatments for end-stage renal disease in Brazil. These results, however, are not suitable for a comparison with the value of a statistical life (year) estimated within the contingent valuation survey carried out in this study. The main reason relates to the costs measured in Sesso *et al.*, (1990), which considered only part of the total costs associated with the treatments – the direct and indirect medical costs. It can be regarded, at best, as a lower bound of the value of a statistical life year in Brazil.

7.1.2. Non-medical interventions and other approaches

- Non-medical interventions

An extensive library and Internet search was undertaken in an attempt to identify cost-effectiveness studies of non-medical interventions in Brazil that could provide approximations of the value of a statistical life (year). No suitable study could have been identified in areas such as the transport, energy and environmental sectors. A few studies used benefit transfer of European or the US unit values to express mortality impacts of energy policies in Brazil in monetary terms (e.g. Molnary *et al.*, available at http://www.ipen.br/cen/cent/publicacao/enfir2000_1.html). In addition, an unsuccessful search was undertaken for other sources/studies of estimates of the value of a statistical life (year) in Brazil that used other willingness-to-pay methods, such as the 'compensating-wage' and hedonic-price model. The paucity of original (locally derived) unit values for mortality effects reinforces the relevance of the results obtained in this study for Brazil.

- Other (GDP-based) approaches

Alternative approaches to estimate approximations of the value of a statistical life (year) in monetary terms were presented in Rabl (2004) and Heck (2004). Both authors argue that it is worth exploring complementary approaches to derive the value of a life-year lost given the uncertainties involved with the willingness-to-pay approach, and specifically with contingent valuation studies. For example, Rabl (2004) claims that in view of the lack of reliable and generally accepted guidelines for the value of a statistical life year (VSLY or VOLY), as derived from the value of a statistical life estimated by different methods, it is interesting to have another perspective, by asking how much a rational individual is willing to pay for an extra year of life, assuming life-time expected utility maximisation of rational individuals. In addition, analysts should examine data on actual expenditures for risk reductions in different sectors, and explore non-willingness-to-pay approaches in order to obtain further sources of guidelines on the VSLY.

Heck (2004) proposed the following method for comparing costs and benefits of different risk-reducing measures: to convert the economic costs of these measures into losses of life expectancy and compare with the benefits in terms of gains of life expectancy due to the measures. From these estimates it is possible to generate analytical approximations of years of life lost per dollar lost, and the 'formal' value of a life year lost (FVLYL), as described below. The basic idea of the proposed method was to use the biological measure life expectancy as a basic indicator, comparing life-saving measures according to their direct and indirect effects on life expectancy. The indirect effects include mainly the loss of options related to the loss of money. That is, "if an amount of money is spent on a certain risk-reduction measure like air pollution control, it may lack for alternative measures – e.g. for medical services – which have an influence on life expectancy as well" (Heck, 2004).

The author claims that given the strong correlation between wealth/income and life expectancy, a loss of money due to a certain expense causes a marginal decrease in life expectancy, which can be directly compared to the mortality benefit of the expense. It was formally shown that the change of life expectancy on the individual level due to changes in income could be approximately extracted from the global curve of average life expectancy depending on average incomes. Numerical FVLYL values were derived using the global relationship between national income per capita (GNI per capita and PPP adjusted GNI per capita) and life expectancy. Different fits of the global relationship curve were estimated and their parameters used to predict country-specific FVLYL[94]. Heck (2004) claims that more important than the numerical values presented in his paper is the general trend of the slope of the global curve, which suggests that economic mortality risks due to the loss of an amount of money tend to be bigger in poor countries than in rich countries. Table 74 presents the results for Brazil.

Table 74: GDP-based values of a statistical life year in Brazil (US$ 2001)

Author	Minimum	Maximum
Heck (2004)	34,127	69,539
Based on Rabl (2004)	3,680	14,720

[94] The author stresses that these numerical estimates should be used carefully given the uncertainties involving country-specific data generated from the global relationship between GNI per capita and average life expectancy.

Rabl (2004) derived results for a collective value of a life-year lost for Europe and the ratio of VSLY per GDP per capita that are arguably suitable for policymaking while avoiding ethical dilemmas of assigning lower VSLY for poorer individuals. It is argued that the shift from individual willingness to pay to a representative collective VSLY for an entire country avoids the unethical issue of different VSLY according to income levels, and represents the actual need of policymakers for rational choices (estimates based on individual willingness to pay are summed-up for the entire population as well). The estimation proposed by Rabl (2004) is calculated for the average income and by averaging over the distribution of ages of concern for a policy decision.

The author used GDP per capita and survival data representative for Europe to estimate collective VSLY based on utility maximisation by rational well-informed individuals. The results suggest that VSLY equals to GDP per capita times a factor ranging between 0.5 and 2, depending on age, discount rate and variation of quality of life with age. Table 74 shows estimates derived for Brazil when using Brazilian GDP per capita equal to PPP US$7,360 in 2001[95]. However, these are crude approximations since Rabl (2004) indicates that for application in developing countries the estimates would have to be recalculated with the appropriate (local) survival probabilities. Finally, the author claims that the same approach could also be used to determine the value of a statistical life but it would not be appropriate for accidental deaths or related to air pollution because it does not consider risk aversion of an early death and it does not account for the loss of life expectancy, respectively.

Dowrick *et al.* (1998) proposed a method to estimate the value of life using cross-country data on consumption of specific goods and services to explain variations in life expectancy between countries. The authors found that health care and nutrition consumption are important in determining life expectancy. Also, education is strongly associated with life expectancy since better schooling increases individuals' knowledge about health-promoting behaviour. The cost function for life expectancy in terms of per capita consumption of health care, food and education was used to estimate the marginal cost of an increment in life expectancy for a representative consumer in each country. The cost of a reduction in age-specific mortality rates sufficient to save the life of one person is then estimated for each country, assuming that in each country health

[95] http://www.undp.org/hdr2003/indicator/cty_f_BRA.html

resources are allocated in order to maximise life expectancy. The marginal cost of saving one life in Brazil equalled US$120,544 (US$ 1980).

7.1.3. Summary

It was difficult to find cost-effectiveness studies of both medical and non-medical life-saving interventions in Brazil with the necessary characteristics to allow the comparison of results with our willingness-to-pay-based estimates. These characteristics include, according to the brief review of the cost-effectiveness literature, the use of the physical impact metric (life-expectancy, years of life or lives lost); the real implementation of the intervention (continuously); the inclusion of all costs of the intervention (societal perspective); and having the main purpose of the intervention as to save lives (no joint benefit). It can be concluded that the (few) Brazilian cost-effectiveness studies do not provide suitable results in terms of the comparability with willingness-to-pay-based results, each of them failing to present some of the desired characteristics. The cost-effectiveness results can, at best, be considered as a lower bound for the willingness-to-pay estimates. As can be seen in Figure 5 and Figure 6, the estimates vary significantly, the willingness-to-pay estimates being of an order of magnitude higher, except the results of Vieira *et al.*, (2001).

Figure 5: Comparison of VSL estimates in Brazil

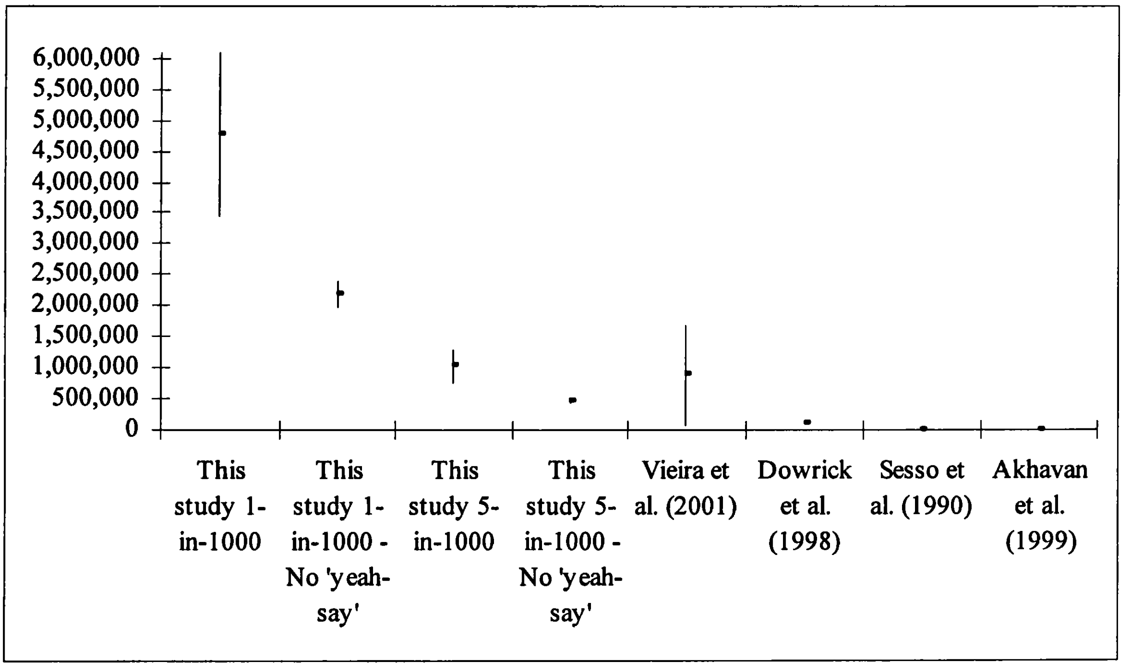
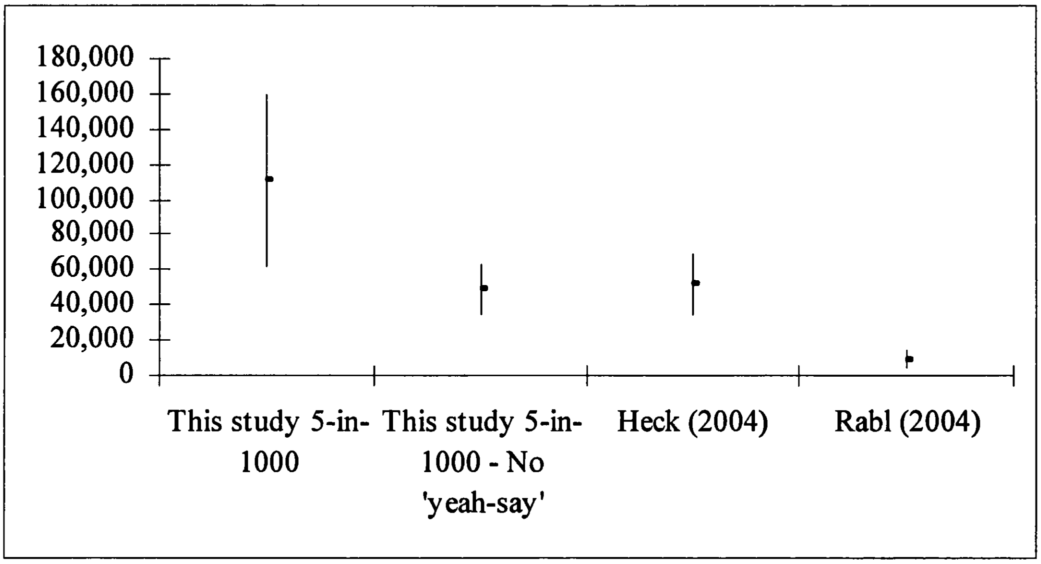


Figure 6: Comparison of VSLY estimates in Brazil



The comparison above reinforces our preference for suggesting the value of a statistical life estimated using the 5-in-1000 immediate risk reduction estimates for policy analysis in Brazil. They are more conservative values than those using the 1-in-1000 risk reduction; they seem to be more reliable estimates because this was the first question posed to the respondents; and they are in line with the cost per life saved obtained in cost-effectiveness studies of life-saving intervention in Brazil when compared with the 1-in-1000 risk reduction estimates. Table 75 summarises the findings.

Table 75: Comparison of VSL and VSLY estimates in Brazil

Study	Higher value	Lower value
Value of a statistical life or cost per life saved		
This study: 5-in-1000	1,306,941	767,187
This study: 5-in-1000 - No 'yeah-say'	489,752	415,381
Vieira *et al.* (2001)	1,694,241	78,534
Dowrick *et al.* (1998)	120,544	120,544
Sesso *et al.* (1990)	25,134	5,943
Akhavan *et al.* (1999)	2,492	2,672
Value of a statistical life year or cost per life-year saved		
This study: 5-in-1000	159,456	61,392
This study: 5-in-1000 - No 'yeah-say'	34,729	62,944
Heck (2004)	69,539	34,127
Rabl (2004)	14,720	3,680
Sesso *et al.* (1990)	12,134	3,022

7.2. Benefit transfer as an alternative to this study's empirical results

In the absence of original stated preference studies in Brazil to estimate the willingness to pay for mortality risk reductions in Brazil, policymaking would have to rely on benefit transfer techniques or the human capital approach to provide estimates of the value of a statistical life. Benefit transfer is the most used technique to generate the value of a statistical life when proper valuation exercises are not possible in developing countries. This section aims to explore the benefit transfer techniques used so far in the environmental economics literature, to generate transferred willingness-to-pay estimates for Brazil, and to examine whether these estimate differ from the estimates produced in this study. The differences between transferred estimates and locally derived estimates using original stated preference studies are known in the literature as benefit transfer errors (Navrud, 2004; Ready *et al.*, 2004). This procedure aims to provide some basis to discuss how important this study's empirical results are for policymaking in Brazil.

7.2.1. Benefit transfer: concepts and conditions

According to Rosenberger and Loomis (2001), benefit transfer is defined as the adaptation and use of existing economic information derived to specific site under certain resource and policy conditions to new contexts or sites with similar resources and conditions. Brouwer (1998) defines it as a technique where the results of monetary (environmental or health) valuation studies, estimated through market based or non-market based economic valuation techniques, are applied to a new policy context. Some authors (e.g. Navrud, 2004) prefer the term 'value transfer', since in many cases damage estimates can also be transferred from previous studies (termed study sites) to new evaluation contexts (policy sites).

When the relevant economic values of different policy alternatives and the required resources are not available for developing new valuation studies to support decision-making, then economic measures estimated in similar contexts and sites can provide a proxy for the estimates necessary for the decision-making. In other words, benefit transfer is an alternative to fill in gaps in the availability of information on the preferences of individuals in a country or region. "Applying previous research findings to similar decision situations is a very attractive alternative to expensive and time consuming original research to quickly inform decision makers" (Brouwer, 1998).

- Alternative benefit transfer methods

Navrud (2004) defines a typology of the most usual benefit transfer methods, identifying two main approaches: (i) the unit value transfer approach, which involves the methods known as simple unit transfer (also known as single-point estimate or average-value transfer – Rosenberger and Loomis, 2001) and unit transfer with income adjustment; and (ii) the function transfer approach that uses the benefit function transfer method and meta-analysis (or meta regression analysis).

- Unit value transfer – simple unit transfer

This is the simplest method of transferring economic estimates from one site or context to another, based on using an estimate from a single relevant study site or a range of point estimates if more than one study is considered relevant (average-value transfer). According to Navrud (2004), it assumes that the well being experienced by an average individual at the original study site will be equivalent to the well being experienced by the average individual in the policy site. Once this assumption holds, analysts can directly transfer the economic benefit or damage from the study site to the policy site. An alternative procedure, average-value transfer, is based on using a measure of central tendency of relevant studies as the transfer estimate for a given policy site. Rosenberger and Loomis (2001) argue that average value estimates, however, are no better than the data they are based on, that is, all of the eventual problems related to the credibility of any single estimate are also relevant for an average value based on that estimates. The authors claim that the primary steps to perform a single point estimate transfer (simple unit transfer) include identifying and quantifying the policy-induced changes, and locating and transferring a unit value (single estimate or average) representing the individuals' welfare measure.

An immediate limitation of this method is that individuals in the policy site may differ from individuals at the study site(s) in terms of socio-economic characteristics – income, education, religion, for example – that can affect their preferences. Therefore, Navrud (2004) concludes that the simple unit transfer approach should not be used for benefit transfer between countries with different income levels and costs of living.

- Unit value transfer – unit transfer with income adjustment

The unit transfer with income adjustment method has been the most used practice for policy analysis in developing countries since most of the environmental valuation studies were conducted in developed countries (Navrud, 2004). This method assumes that the benefit value in the policy site can be estimated by adjusting the benefit value in the study site(s) by the ratio between income levels in both sites and the income elasticity of demand for the good. Formally:

$$B_P = B_s.\left(\frac{Y_P}{Y_s}\right)^{\beta}, \tag{108}$$

where (B_p) is the adjusted policy-site benefit; (B_s) is the original benefit estimate in the study site; (Y_p) and (Y_s) are the income levels; and (β) is the income elasticity of demand for the analysed good.

However, it is argued that most studies assume GDP per capita as proxies for income in international benefit transfers, and income elasticity of demand equal to one. These common assumptions do not necessarily hold. Navrud (2004) argues that it is appropriate to use PPP estimates of per capita GDP, instead of GDP per capita, since these estimates are adjusted to reflect a comparable amount of goods and services that could be purchased with the per capita GDP in other country. Also, the author claims that there is no evidence that welfare measures associated with environmental goods vary proportionally with income, and sensitivity analyses should assume different levels of income elasticity of demand. Using an income elasticity equal to one would change the willingness-to-pay measure in the policy site proportionally to the relative per capita income differential across the two areas of study, whilst income elasticity equal to zero would mean that no adjustment is considered for income differentials (Davis *et al.*, 1999).

- Function transfer – benefit function transfer

Benefit-function transfer involves the use of a willingness-to-pay function, derived in a study site preferably using stated or revealed preference techniques, which relates willingness to pay to a set of characteristics of the study-site population and the environmental good. That is, benefit function transfers use a model that statistically relates benefit measures with study factors such as characteristics of the user population and the resource being evaluated. The transfer process involves adapting the benefit function to the characteristics and conditions of the policy site, forecasting a benefit measure based on this adaptation of the function, and use of the forecast measure for policy analysis (Rosenberg and Loomis, 2001).

The advantage of benefit function transfer, in contrast with unit value transfer, is that more information can be taken into account in the transfer process. When transferring a unit value estimate from a study site to a policy site, it is assumed that the two sites are identical across the various factors that determine the level of benefits derived in both sites. However, Rosenberger and Loomis (2001) argue that this is not always the case, their argument being based on different validity and reliability assessments of unit value transfers. The invariance involving the transfer of benefit measures alone makes these transfers insensitive or less robust to significant differences between the study site and the policy site. Therefore, the main advantage of transferring an entire benefit function to a policy site is the apparently increased precision of tailoring a benefit measure to fit the characteristics of the policy site.

Disadvantages of this method are primarily due to data collection and model specification in the original study. Navrud (2004) claims that the main problem with the benefit function approach relates to the exclusion of relevant variables in the willingness-to-pay function estimated in a single study. For example, when the estimation is based on observations from a single environmental good, the lack of variation in some of the independent variables avoids the inclusion of these variables in the model, and in another policy site these variables may be important. Indeed, Rosenberg and Loomis (2001) report that factors in the benefit function may be relevant to the study site but not to the policy site. These factors can have distinct effects on the tailored benefit measures at a policy site.

- Function transfer – meta-analysis

Meta-analysis is used when the results of many valuation studies, developed in different study sites, are used for estimating a single benefit transfer function. It is defined as the statistical summary of relationships between benefit estimates and quantifiable characteristics of studies. In meta-analysis, several studies are analysed as a group and each result of these studies is one observation in a regression analysis. The data for a meta-analysis is typically summary statistics from study-site reports and includes quantified characteristics of the user population, study site's environmental resources, and valuation methodology used.

Navrud (2004) claims that meta-analysis allows analysts to evaluate the influence of a wider range of population and environmental good characteristics, as well as the modelling assumptions. The resulting regression equations can then be used to predict an adjusted unit value for the policy site, given the availability of data on the independent variables for the policy site. The meta-analysis regression has the welfare measure as dependent variable, the environmental good and population characteristics as independent variables (similar as the benefit function transfer), but also includes characteristics of the original studies in the study sites. These characteristics include methodological variables, such as elicitation format, payment vehicle, and response rates in case of studies applying stated preference methods. However, the author argues that methodological variables are not particularly useful in predicting welfare estimates for environmental goods, especially in international benefit transfer, if we assume cross-country heterogeneity in preferences for environmental goods. The author concludes that to increase the applicability of meta-analysis for benefit transfer, analysts should select original studies that are methodologically very similar to each other, isolating the effects of site and population characteristics on the estimates.

- Validity and reliability of benefit transfer

Several factors were identified that can affect the reliability and validity of benefit transfers (Rosenberger and Loomis, 2001). One group of factors that affects the validity of benefit transfers includes (i) the quality of the original study greatly affects the quality of the benefit transfer process; (ii) the limited number of studies investigating a specific environmental good, thus restricting the pool of estimates and studies from which to draw information; and (iii) the documentation of data collected and reported can be a limitation.

A second group of factors is related to methodological issues. For example (i) different research methods may have been used across study sites, including what question(s) was asked, how it was asked, what was affected by the management or policy action, how the environmental impacts were measured, and how these impacts affect recreation use; (ii) different statistical methods for estimating models can lead to large differences in values estimated, including issues such as the overall impact of model misspecification and choice of functional form; and (iii) there are different types of values that may have been measured in primary research, including use values and/or passive- or non-use values.

A third group of factors affecting the validity of benefit transfers regards the correspondence between the study site and the policy site, which arises because (i) some of the existing studies may be based on valuing activities at unique sites and under unique conditions; (ii) characteristics of the study site and the policy site may be substantially different, leading to quite distinct values.

A fourth validity factor is the issue of temporality or stability of data over time. If the existing studies occurred at different points in time, relevant differences between then and now may not be identifiable nor measurable based on the available data. The fifth factor is the spatial dimension between the study site and the policy site. This includes the extent of the implied market, both for the extent and comparability of the affected populations and the resources impacted between the study site and the policy site. All these factors can lead to bias or error in the benefit transfer process, reducing its robustness. The objective of the benefit transfer process is to minimize mean square error between the true value and the predicted or transferred value of impacts at the policy site. However, Rosenberger and Loomis (2001) claim that the original or true values are themselves approximations and are subject to error. Therefore, any information transferred from a study site to a policy site is accomplished with varying degrees of confidence in the applicability and precision of the information.

- Conditions and limitations of benefit transfer

Rosenberger and Loomis (2001) argue that some general conditions should be met to perform benefit transfers. First, the policy context should be carefully defined, identifying (i) the extent, magnitude, and quantification of expected impacts from the proposed action; (ii) the population that will be affected by the expected impacts; and (iii) the data needs, including the type of measure (unit, average, marginal value) and the degree of certainty surrounding the transferred data. Second, the study-site data should also meet certain conditions, such as (i) studies transferred must be based on adequate data, valid economic method, and correct empirical technique; (ii) contain information on the statistical relationship between benefits and socio-economic characteristics of the affected population; and (iii) contain information on the statistical relationship between the benefits and physical/ environmental characteristics of the study site.

Finally, the correspondence between the study site and the policy site should ideally have specific characteristics such as (i) the environmental resource and the change in the quality or quantity of the resource at the study site and the resource and expected change at the policy site should be similar; and (ii) the markets for the study site and the policy site are similar, unless there is enough usable information provided by the study on own and substitute prices – other characteristics should be considered, including similarity of demographic profiles between the two populations and their cultural aspects.

7.2.2. Benefit transfer validity tests

Studies have tested the validity and reliability of different benefit transfer methods and results have shown that the uncertainty in spatial and temporal benefit transfer can be large (e.g. Ready *et al.*, 2004; Kristoferson and Navrud, 2005). Although no standard protocol or guidelines for conducting benefit transfer is available, some studies compare benefit transfer estimates with contingent valuation studies of the same site to test the validity of benefit transfer. For example, Bergland *et al.* (1995), cited in Navrud (2004), conducted contingent valuation surveys for increasing water quality in two different lakes in Norway, generated benefit functions for each of them, transferred the benefit function to each other, and then compared the transferred values with the original contingent valuation estimates. The authors also transferred and compared the mean (unit) values, since the lakes were rather similar in size and type of pollution problem. Several tests for transferability were conducted but transferred and original estimates were statistically different at the 5% level. However, the transfer error[96] varied between 20% and 40%, with predicted values being lower in one case (for one of the lakes) and higher for the other lake. Finally, Navrud (2004) cites examples of validity tests performed in-country, cross-countries, and between developed and developing countries, and concluded that the results from these studies show that the uncertainty in value transfer can be large. The general indication is that benefit transfer cannot replace original studies, especially when the costs of being wrong are high.

Ready *et al.* (2004) measured the benefits for specific health impacts related to air and water pollution in five European countries using similar contingent valuation surveys. The authors tested different benefit transfer methods against original contingent valuation estimates, finding an average error of 38%. They concluded "accounting for measurable differences among countries in health status, income and other demographic measures, either through ad hoc adjustments to the transferred values or through value transfer function transfer, did not improve transfer performance" (Ready *et al.*, 2004). It suggests that cultural and attitudinal factors seem to be important in explaining differences in valuation across countries. Finally, Ready *et al.*, (2004) claimed that some of the differences between predicted and original estimates might be due to some amount of sampling error in the target country estimate, and proposed the use of Monte Carlo techniques to simulate what would occur if the same survey was undertaken many times in the country. This procedure can arguably produce more accurate error estimates.

As seen before, the usual benefit transfer methods are (i) unit (mean and median) value transfer (UVT), (ii) unit value transfer with income adjustments (UVTA), and (iii) willingness-to-pay or benefit function transfer (BFT), in which predicted willingness to pay in the policy site are estimated using the willingness-to-pay function estimated in study sites and individuals' characteristics set equal to the average from the policy site sample. The transfer of benefit functions is, initially, preferred to the transfer of average unit values since more information about the willingness-to-pay estimates can be used in the estimation of transferred values (e.g. Brower and Spaninks, 1999). However, some authors (e.g. Bergland *et al.*, 1995) advocate that both willingness-to-pay functions and unit values should be transferred and tested. For example, Muthke and Holm-Mueller (2004) analysed the forecasting quality of benefit transfer by comparing results of two German contingent valuation studies with two Norwegian studies that applied a similar methodology. They concluded that there was no clear increase in accuracy when applying the benefit transfer function method to their samples, suggesting that adjusting the primary study with the income ratio is more advantageous than transferring a complete benefit function.

Brower and Spaninks (1999) summarised the different validity tests in the international literature (Table 76). The first set of validity tests is appropriate to the unit value and income-adjusted unit value transfer methods. The mean and median willingness-to-pay estimates at the policy and study sites can be tested using parametric (e.g. t, Wald) and non-parametric (e.g. Mann-Whitney) tests. Equality of the distribution

[96] Usually defined as the difference between transferred mean WTP and observed mean WTP, as a percentage of the observed mean WTP (Navrud, 2004; Ready *et al.*, 2004)

of individual willingness-to-pay values at the policy ($WTP_{p,i}$) and study sites ($WTP_{s,i}$) can be tested using the Kolmogorov-Smirnov test. The second and third groups of hypothesis refer to the benefit function transfer. Brower and Spaninks (1999) claim that for a valid benefit function transfer the estimated coefficients of the willingness-to-pay function should be equal in policy and study sites ($\beta_p = \beta_s$). "If the coefficients of explanatory variables are not the same at different sites, their impact will be different at these sites and hence the model estimated at one site cannot be used to predict willingness to pay at another site" (Brower and Spaninks, 1999). The second group of hypothesis compare the coefficients directly whereas the third hypothesis compares the coefficients with the pooled model using both samples. According to Muthke and Holm-Mueller (2004) this test is weaker than comparing the coefficients directly since the pooled parameter (β_{p+s}) already comprehend information of the policy and study sites.

Table 76: Validity tests for benefit transfer

Transfer	Null hypothesis	Test
UVT / UVTA	I – Average WTP at policy site = average WTP at study site	t-test / Mann-Whitney test
	I – Distribution $WTP_{p,i}$ = Distribution $WTP_{s,i}$	Kolmogorov-Smirnov test
BFT	II – $\beta_p = \beta_s$	Lagrange multiplier / Wald test
	II – $\sigma^2_p = \sigma^2_s$ (explained variance at policy and study sites)	Chow / Likelihood ratio test
	III – $\beta_{p+s} = \beta_p = \beta_s$	Lagrange multiplier / Wald test
	III – $\sigma^2_{p+s} = \sigma^2_p = \sigma^2_s$	Chow / Likelihood ratio test
	IV – $WTP_{pp} = f(\beta_s, X_p) = WTP_p$	t-test / Mann-Whitney test
	IV – Distribution $WTP_{pp,i}$ = Distribution $WTP_{p,i}$	Kolmogorov-Smirnov test
	IV – $WTP_{ss} = f(\beta_p, X_s) = WTP_s$	t-test / Mann-Whitney test
	IV – Distribution $WTP_{ss,i}$ = Distribution $WTP_{s,i}$	Kolmogorov-Smirnov test

Source: Adapted from Brower and Spaninks (1999) and Muthke and Holm-Mueller (2004)

A fourth group of hypothesis involves using the estimated willingness-to-pay function in the study site (β_s) and the explanatory variables of the policy site (X_p) to predict mean and median willingness to pay in the policy site (WTP_{pp}) and compare it with the observed actual average willingness-to-pay estimate in the policy site (WTP_p). The same procedure can be undertaken using the benefit function of the policy site to predict estimates in the study site (WTP_{sp}) and compare it with the observed estimate in the study site (WTP_s). Also, the test of equal distribution of the observed willingness-to-pay values can be performed.

Finally, Kristoferson and Navrud (2005) suggested the use of equivalence tests as a more appropriate hypothesis test of benefit-function transfer. The authors claim that the usual validity tests state a null hypothesis of no difference between an original study result and a benefit transfer estimate. Rejection of this hypothesis is interpreted as evidence against the validity of benefit transfer, and non-rejection as evidence for validity. They argue that the heterogeneity of environmental goods does not support the usual equality test since willingness to pay for an environmental good would be expected to be equal in different sites only if the functional form of the indirect utility functions in two populations are the same, and the vector of prices and the vectors describing environmental quality are identical. In equivalent tests the null hypothesis is that values are different, and only through rejection of the null hypothesis it can be concluded that the values are equivalent. It demands the definition of an interval within which estimates are regarded equivalent, also known as 'limit of tolerance' – the level of benefit transfer error that the researcher is willing to accept (Muthke and Holm-Mueller, 2004).

- Benefit transfer errors

The approach used to test the validity of transferred willingness-to-pay estimates to Brazil is to compare these estimates with those obtained in the contingent valuation survey in Brazil and estimate the magnitude of the benefit-transfer 'errors'. A UK benefit function is used to estimate adjusted willingness-to-pay estimates for Brazil according to the socio-economic differences between Brazil and the UK. The UK estimates and willingness-to-pay functions are used in this analysis because (i) the survey instrument is identical in Brazil and in the UK, (ii) the good evaluated is the same in both studies (small risk reductions in probabilities of death), (iii) the statistical models used to generate mean and median estimates are identical, and (iv) the sample sizes are similar. These characteristics seem to guarantee that potential differences between estimates can be attributed to differences in respondents' preferences, minimising differences due to methodological divergences.

The UK mean and median willingness-to-pay estimates for immediate risk reductions were transferred to Brazil using the unit value transfer (direct transfer) and the income-adjusted unit value transfer assuming different income elasticity of willingness to pay (ε):

$$transferred\ WTP = WTP_{UK}.\left(\frac{income_{br}}{income_{uk}}\right)^{\varepsilon} \tag{109}$$

The parameters used to transfer the UK unit values were the income elasticity of willingness to pay equal to one and equal to 0.4 ($\varepsilon=1$ and $\varepsilon=0.4$, Alberini *et al.*, 1997) and the US$ 2003 GDP per capita adjusted by PPP equal to US$27,700 in the UK and US$7,600 in Brazil[97]. The adjusted transferred values are shown in Table 78.

The UK willingness-to-pay functions used to estimate transferred values to Brazil considered individuals characteristics that were statistically significant in the validity tests in the UK (income and education), and in Brazil (mainly income). The benefit transfer functions were estimated as follows[98]:

Model 1: $$WTP_{UK1} = f(income, education) \quad (110)$$

Model 2: $$WTP_{UK2} = f(income)$$

Table 77: the UK Willingness-to-pay for immediate risk reductions – Weibull distribution

5-in-1000	Model 1		Model 2	
Regressors	Coefficient	Standard error	Coefficient	Standard error
Constant	7.4324 (*)	0.5795	5.8402(*)	0.1792
Income (thousand)	0.0205(**)	0.0122	0.0114	0.0119
Years of schooling	-0.1248(*)	0.0420	---	---
Scale parameter	1.2549		1.2864	
N	313		318	
Log likelihood	-392.8674422		-402.8587966	
1-in-1000				
Constant	6.6125 (*)	0.7320	5.0457(*)	0.2135
Income (thousand)	-0.0151	0.0135	-0.0234(**)	0.0129
Years of schooling	-0.1234(**)	0.0537	---	---
Scale parameter	1.9342		1.9406	
N	313		318	
Log likelihood	-365.317992		-377.7138731	

Notes: (*) significant at 1%; (**) significant at 10%.

Table 77 shows the models' estimated coefficients that were combined with the Brazilian sample's averages (annual income and years of education), which are similar to the Sao Paulo population figures[99], to produce the benefit-function transferred values, shown in Table 78. Wald tests of equality between the coefficients in Table 77 and the corresponding coefficients using the Brazilian sample (test II in Table 76) resulted in

[97] http://www.worldfactsandfigures.com/gdp_country_desc.php

[98] These UK willingness-to-pay models were estimated using SAS 8.0, in contrast with all other models in this work that were estimated using STATA 6.0. The reason is that STATA deals with interval data with no upper limit (missing value) differently than SAS. The Brazilian study considered the willingness-to-pay intervals bounded by individuals income (Chapter 4), while the UK study did not bound these intervals. SAS was used in order to obtain the same results as presented in the literature (Alberini *et al.*, 2004a).

[99] For example, the average annual individual income in the sample equalled R$10.137,81 while the figure relative to Sao Paulo's population is R$12.665,00.

null hypothesis of equality being rejected for all models and risk reductions. The benefit transfer errors were estimated as defined by equations (111), and represent the percentage deviations between the transferred values and the locally estimated willingness to pay in Brazil.

$$Benefit\ transfer\ error\ I = \frac{|transferred\ WTP - WTP_{BR}|}{WTP_{BR}}$$

$$Benefit\ transfer\ error\ II = \frac{|transferred\ WTP - WTP_{\mathrm{BR\ no\ 'yeah\ -\ saying'}}|}{WTP_{\mathrm{BR\ no\ 'yeah\ -\ saying'}}} \qquad (111)$$

Table 78: Benefit transfer values and errors – WTP for immediate risk reduction

Risk reduction	5-in-1000		1-in-1000		Avg transfer error
	Mean	Median	Mean	Median	
Brazil	**653** (528-817)	**384** (328-434)	**610** (490-767)	**346** (303-393)	---
Brazil - excluding 'yeah-saying'	**245** (208 - 290)	**208** (185 – 233)	**241** (202 - 291)	**197** (173 - 224)	---
UK unit value transfer	**802**	**422**	**360**	**96**	---
Benefit transfer error I	22.8	9.9	41.0	72.3	36.5
Benefit transfer error II	227.3	102.9	49.4	51.3	107.7
Income-adjusted UK transfer (e=1)	**220**	**116**	**99**	**26**	---
Benefit transfer error I	66.3	69.8	83.8	92.4	78.1
Benefit transfer error II	10.2	44.3	59.0	86.6	50.0
Income-adjusted UK transfer (e=0.4)	**478**	**252**	**215**	**57**	---
Benefit transfer error I	26.8	34.5	64.8	83.5	52.4
Benefit transfer error II	95.1	20.9	11.0	71.0	49.5
UK benefit function transfer 1	**268**	**149**	**138**	**36**	---
Benefit transfer error I	59.0	61.2	77.4	89.6	71.8
Benefit transfer error II	9.3	28.5	42.8	81.7	40.6
UK benefit function transfer 2	**131**	**71**	**68**	**18**	---
Benefit transfer error I	79.9	81.6	88.8	94.9	86.3
Benefit transfer error II	46.4	65.9	71.7	91.0	68.7

Notes: Benefit transfer values in US$ (95% confidence interval); benefit transfer errors in percentage.

As can be seen in Table 78, while the benefit transfer estimates can be significantly different from the locally derived Brazilian willingness-to-pay estimate, quite a few transferred estimates were inside the 95% confidence interval of the corresponding Brazilian estimate. When transferred values were compared with the full sample estimates only the UK unit value transfer – both mean and median willingness to pay for a 5-in-1000 risk reduction – fell inside the 95% confidence interval of the Brazilian estimates. When the sample without 'yeah-saying' respondents is considered the following transferred estimates ranged between the corresponding 95% confidence interval: income-adjusted (e=1) mean value for a 5-in-1000 risk reduction; income-adjusted (e=0.4) mean values for the 1-in-1000 risk reduction; and the transferred mean value (5-in-1000 risk reduction) using the benefit function 1 (income and education as explanatory variables). These results are expected, given the peculiarities of the Brazilian figures, such as the lack of proportionality between estimates for different risk reductions and the unexpectedly high willingness-to-pay values presented, which make the Brazilian results appear similar to developed countries' estimates. In this circumstance, it is expected that the transferred unit values for the 5-in-1000 risk reduction range between the 95% confidence interval of the Brazilian estimates, while the same is not true for the smallest risk reduction. When the estimates excluding 'yeah-saying' respondents are compared with transferred estimates other income-adjusted transferred values are within the corresponding 95% confidence interval, but still not consistently.

Due to the peculiar characteristics of the Brazilian estimates referred above, it is not surprising that the direct transfer of the UK unit values outperformed other transfer methods when transferred values were compared with values estimated using the full sample (benefit transfer error I), presenting the lowest average benefit transfer error of 36.5%. When 'yeah-saying' respondents were excluded the mean and median values were smaller than the figures of the full sample. In this case, transfer methods that adjust estimates according to the policy-site population characteristics presented better results (benefit transfer error II) than the direct unit value transfer. The average benefit transfer error of the characteristics-adjusting transfer methods was approximately 52%, with the best performance presented by the willingness-to-pay function with education and income as explanatory variables (40.6%). Surprisingly, the worst performance among these adjusting transfer methods related to the other benefit transfer function tested, which included only income as regressor (68.7%).

The results of this benefit transfer exercise suggest that if the willingness-to-pay function is available and its specification follows the statistical significance criteria then it can be the preferred alternative to undertaking original stated preference studies in the policy site. That is, if the benefit function can be specified with the significant explanatory variables in the study site then the transfer results can outperform other transfer methods results, whereas a misspecification of the benefit function, as apparently is the case with the benefit transfer function 2, can result in higher transfer errors. In any case, it seems that the income-adjusted unit value transfer can be an interesting alternative to original stated preference studies in developing countries since its average transfer errors – approximately 50% - lie between the range of errors produced by different benefit transfer functions.

Notwithstanding all the problems, however, it is important to note that the average benefit transfer results are in line with Ready *et al.*, (2004). Their benefit transfer tests in five European countries showed overestimations as high as 230% and underestimations as high as 77% while the majority of transfers resulted in errors less than 50% (average error 38%). Alberini *et al.*, (1997) found benefit transfer errors ranging between 29% and 54% when testing willingness to pay for health occurrences in the US and in Taiwan.

7.2.3. Summary

In the absence of the value of statistical life estimates locally derived in Brazil using stated- or revealed preference techniques, policy analyses would have to rely on benefit transfer to estimate the benefits of air pollution control policies in Brazil. It is acknowledged that the willingness-to-pay estimates generated using the contingent valuation survey in Brazil have a number of uncertainties regarding the assumptions adopted, for example, the assumed distribution of willingness to pay, parametric versus non-parametric results, value of a statistical life derived from mean versus median willingness to pay; value of a statistical life derived from 1-in-1000 or 5-in-1000 risk reduction. However, these results can be compared with estimates generated under equivalent assumptions in different countries, a major advantage of having used the same methodology as in other countries.

The UK results were used to estimate the percentage difference between transferred estimates to Brazil and locally derived estimates (benefit transfer errors) using different benefit transfer methods. The transferred estimates when compared with the results obtained using the full sample in Brazil (with potential 'yeah-saying' respondents) presented average transfer errors equal to 69%, the direct unit value transfer outperforming other transfer methods with the smallest average benefit transfer error (36.5%). This result can be explained by the unexpected high values observed in this study most likely because of the cooperative behaviour of part of respondents. When the same analysis is undertaken excluding the cooperative respondents, the average benefit transfer error equals 63% - this average falls to 52% if only the income-adjusting transfer methods are considered.

The results of this benefit transfer exercise do not allow us to conclude which benefit transfer method would be preferable in case an original valuation study would not be possible in developing countries. Indeed, it shows that benefit transfer errors may be as high as 200% in some cases. It can be an alternative method to generate estimates of the value of a statistical life when the resources for an original valuation study are not available and the accuracy of the estimates are not relevant for policy analysis. This is not, however, true in the case of policy analysis relating to air pollution, for which the mortality effect is the main impact and, therefore, requires estimates of the value of a statistical life to be as accurate as possible for policy evaluation.

7.3. Study cases

Chapter 5 described the survey instrument and statistical methods used to obtain the value of a statistical life in Brazil, while Chapter 6 (section 4) compared the Brazilian results with similar estimates of the value of a statistical life in other countries using the same valuation methodology. Previously, Chapter 4 reviewed the international literature that presented estimates of the value of a statistical life obtained with other valuation techniques and meta-analyses in different countries. The previous sections in this Chapter were devoted to the comparison of the estimates of the value of a statistical life (and life year) obtained in this study with other estimates for Brazil obtained with non-valuation methods (e.g. alternative national income-based approaches), cost-effectiveness analysis, and benefit transfer methods.

This section aims to evaluate the impact that our estimates could have in policy analysis in Brazil by comparing the results of two cost-benefit analyses that relied on benefit transfer methods with the cost-benefit results using the estimates provided by this study. It aims to highlight the importance of our results in reducing the uncertainties of policy analyses that include the reduction of mortality among their main effects. It starts with a brief description of the regulatory framework regarding air pollution in Sao Paulo, Brazil (sub-section 7.3.1), followed by an analysis of a national programme to control vehicle emissions in Brazil – Proconve (sub-section 7.3.2), and the analysis of a local programme to improve urban transportation in Sao Paulo aiming to reduce air pollution – PITU (sub-section 7.3.3).

7.3.1. The regulatory framework regarding air pollution in Sao Paulo

The institutions responsible for environmental policies in Sao Paulo are the federal government, state authorities, and municipal government agencies (Omarsal and Ganton, 1997)[100]. At federal level decisions are made regarding general policy guidelines, laws, standards, and budget, mainly through the National Environmental Council (CONAMA[101] – "*Conselho Nacional do Meio Ambiente*", created in 1981), the Ministry of the Environment, and the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA). At the state level the Environmental Sanitation Technology Company (CETESB), part of the state Secretariat of the Environment, is the environmental protection institution responsible for monitoring air pollution in Sao Paulo. CETESB is in charge of licensing new industrial installations, monitoring air quality, and enforcing state pollution control legislation. The municipality of Sao Paulo is responsible for traffic managing, licensing taxis and operating bus lines through the Municipal Public Bus Company (CMTC).

Omarsal and Ganton (1997) reported that with regard to vehicular air pollution, CETESB has supported federal environmental agencies in reducing vehicular air pollution. For example, CETESB helped to prepare the CONAMA Resolution that established the Programme to Control Air Pollution from Motor Vehicles (PROCONVE) at the national level, the first case study analysed below. CETESB also prepared the CONAMA resolution that established emission limits for used cars and associated testing procedures. CETESB also designed a programme to control air pollution from motor vehicles in the State of Sao Paulo. The objective of this programme was to integrate the air pollution control efforts of CETESB with other institutions involved in the public transport sector (e.g. the Sao Paulo Metro Company and municipalities within the Sao Paulo metropolitan region – SPMR). The PITU programme, our second case study, is among the results of this initiative of CETESB.

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[100] A complete description of the development of the regulatory framework regarding environmental issues in Brazil is available at the World Bank, http://www.worldbank.org/nipr/brazil/braz-over.htm

[101] CONAMA is the consultation and deliberating organism of the National Environmental System (SISNAMA). It is composed by technical chambers and working groups, representing all sectors of the Brazilian society interested in environmental issues. The president of CONAMA is the Ministry of the Environment, and its executive secretary is the Ministry's Executive Secretary. The council's meetings are open to the general public (http://www.mma.gov.br/port/conama/index.cfm).

7.3.2. PROCONVE – Programme for control of air pollution from mobile sources

Motor vehicles are the main source of air pollution in the Sao Paulo metropolitan region, where private cars were responsible for 75% of carbon monoxide (CO), 73% of hydrocarbons (HC), 23% of nitrogen oxides (NO_X) and 10% of particulate matter (PM) emissions in 1997 in São Paulo (Ferraz and Seroa da Motta, 2001). In 1995 the region's automotive fleet consisted of about 5.16 million vehicles that were responsible for 96% of CO, 90% of HC, 97% of NOx, 86% of SO2, 42% of PM emissions, whereas industry contributed 46% of all PM emitted in Sao Paulo MR in 1995 (Omarsal and Ganton, 1997). In addition, given its geographic characteristics, São Paulo is subject to thermal inversions that can lead to increasing accumulation of atmospheric pollutants (Saldiva *et al.*, 1995).

In order to reduce air pollution levels in Brazilian urban areas, the government implemented in 1986 the PROCONVE programme[102], establishing emission standards for new vehicles produced in or imported to Brazil. PROCONVE, which was based on the international experience (mainly the US) on emission standards, also aimed to promote and develop technology for sampling and analysing pollutants; to create vehicles inspection and maintenance programmes; to promote public awareness of the vehicular air pollution problem; and to establish a criterion for evaluation of the programme's results. The programme considered automotive vehicles in three segments[103] and for each group, a specific adjustment schedule was established. According to Ferraz and Seroa da Motta (2001), the adjustment schedule considered three phases. Phase one was implemented gradually between 1988 and 1991 with specific adjustment schedules for some car models that were allowed a six-month period of adjustment. Phase two started with the limits imposed for 1992 until 1997. The third phase started in 1997 aiming to induce manufacturers to apply the best technology available for emission control. The PROCONVE protocol was successfully implemented from 1988 to 1997 and the average emission levels decreased considerably, as can be seen in Table 79.

As a consequence of the induced emission levels reduction observed between 1988-1997 it is believed that the Proconve programme contributed to the avoidance of a

[102] CONAMA Resolution 18/86 established PROCONVE and was subsequently complemented by nine other resolutions and Federal Law 8723 of October 1993 (Omarsal and Ganton, 1997).

considerable number of disease occurrences and deaths in São Paulo during that period and later. The epidemiologic literature suggests that the reduced exposure to pollutants should have reduced the number of respiratory and cardiovascular deaths, hospital admissions and other health outcomes. Pinheiro *et al.* (2004) analysed health impacts of the PROCONVE program in Sao Paulo during two periods in the nineties – 1991/1994 and 1997/2000, concluding that the PROCONVE programme contributed to avoiding up to 4,500 deaths. To analyse the health impacts of PROCONVE, the authors used air quality data (PM_{10}, SO_2, CO, O_3), minimum temperature, and relative humidity from 1991 to 2000; mortality data for young children (<2 years) and the elderly (>64 years) – total deaths, respiratory deaths and cardiovascular deaths; and a number of epidemiologic studies undertaken in Sao Paulo with the respective age groups. In addition, that study assumed that most of the benefits from improvement in air quality in Sao Paulo during the nineties resulted from the PROCONVE programme.

Table 79: Average emission level for new automobiles in Brazil

Year	Fuel type	CO (g/km)	HC (g/km)	NO_x (g/km)
Prior to 1980	Gasoline	54	4.7	1.2
1986 – 1987	Gasoline	22	2.0	1.9
	Ethanol	16	1.6	1.8
1988	Gasoline	18.5	1.7	1.8
	Ethanol	13.3	1.7	1.4
1992	Gasoline	6.2 (-78%)	0.6 (-75%)	0.6 (-63%)
	Ethanol	3.6 (-79%)	0.6 (-63%)	0.5 (-58%)
1997	Gasoline	1.2 (-96%)	0.2 (-92%)	0.3 (-81%)
	Ethanol	0.9 (-95%)	0.3 (-84%)	0.3 (-75%)
2000	Gasoline	0.73 (-97%)	0.13 (-95%)	0.21 (-87%)
	Ethanol	0.63 (-96%)	0.18 (-89%)	0.21 (-83%)
2003	Gasoline	0.40 (-98%)	0.11 (-95%)	0.12 (-93%)
	Ethanol	0.77 (-95%)	0.16 (-90%)	0.09 (-93%)

Note: (%) refers to the decrease of emissions when compared with 1985 vehicles.
Source: Adapted from Ferraz and Seroa da Motta (2001) and IBAMA (2004), "PROCONVE/PROMOT", 2nd edition, Brasilia: Colecao Meio Ambiente. Serie Diretrizes – Gestao Ambiental, 2.

The dose-response functions used to estimate the mortality effect of the PROCONVE programme are shown in Table 80. Pinheiro *et al.* (2004) describes the time-series analyses that were carried out, fitting generalized linear Poisson regression models for each one of the outcomes and controlling for long-term trend, temperature and humidity. The authors adopted a semi-parametric smooth function due to the non-linear dependence of the adopted endpoints on those covariates. When necessary,

[103] Light vehicles for passenger use, light vehicles for commercial use and heavy vehicles.

autoregressive terms were included in the models to minimize the autocorrelation of the residuals. The 95% confidence intervals were estimated assuming normality of the residuals.

Table 80: Association between mortality and air pollutants

Outcomes	Air Pollutant and lag structure	Regression Coefficients	Standard Error	Air Pollution IQR[1]	
				91-94	97-00
FETAL	NO2[2] (5-day moving average)	0.0013	0.0003	162	97.8
> 64 YEARS					
Total	PM10 (lag 0-1)	0.00081	0.00017	65.75	51.5
	CO (lag 0-1)	0.00831	0.00203	5.75	3.1
Respiratory	PM10 (lag 0-1)	0.00144	0.00039	65.75	51.5
	SO2 (lag 0-1)	0.00311	0.00134	18.5	16.5
Cardiovascular	SO2 (lag 0-1)	0.00199	0.0008	18.5	16.5
	CO (lag 0-1)	0.00704	0.00286	5.75	3.1

Note: 1 interquartile range; 2 $\mu g/m^3$.
Source: Adapted from Pinheiro *et al.* (2004)

The relative risk (RR) of a given endpoint (Y) was estimated as the exponential of the regression coefficient (β) of the air pollutant times air pollution concentration (MPol):

$$RR(Y) = \exp(\beta * \mathrm{MPol}) \qquad (112)$$

Pinheiro *et al.* (2004) showed that the relative risks of all outcomes decreased from the first to the second period, which is expected since air pollutant concentrations declined in the 1990s. Relative risks associated with SO_2 exposure were those that presented the lower decrease reflecting the small change in the pollutant concentration. The number of deaths attributed to a given air pollution concentration at a given period (t) was given by:

$$\mathrm{E}\left[\mathrm{Events}\left(\mathrm{MPol}_t\right)\right] = \left[\exp\left(\beta * \left(\mathrm{MPol}_t\right)\right) - 1\right] * \textit{Total Events}_t, \qquad (113)$$

where (*Total Events*) refers to the total number of outcomes (deaths). It was assumed that the effects were linear, without thresholds. Table 81 presents the estimated deaths attributed to air pollution in the studied periods. SO_2 was the pollutant that presented the smallest concentration decrease among all primary pollutants. On the other side, its concentrations have not reached the standards, neither the daily nor the annual standards, since the eighties. Since the number of deaths attributed to SO_2 effects in the second period was greater than in the first period, there were not any avoided events. However, even though the number of events was greater, the percentage contribution of SO_2 on total, respiratory, and cardiovascular deaths dropped from 1991-1994 to 1997-2000 (Pinheiro *et al.*, 2004).

Table 81: Avoided mortality events due to the Proconve Programme in São Paulo

		Total deaths		Deaths attributable to air pollution		Avoided Events
		1991-1994	1997-2000	1991-1994	1997-2000	
Fetal		12,565	11,250			
	NO2			2,945	1,525	1,420
>64						
Total		182,320	215,402			
	PM10			9,973	9,175	798
	SO2			11,513	12,091	-578
	CO			8,923	5,621	3,302
Respiratory		26,603	31,110			
	PM10			2,642	2,395	247
	SO2			1,575	1,638	-63
Cardiovascular		88,019	99,581			
	SO2			3,301	3,324	-23
	CO			3,636	2,197	1,439

Source: Adapted from Pinheiro *et al.* (2004).

The avoided deaths due to the PROCONVE programme were multiplied by the value of a statistical life to produce the mortality benefit of the policy. The authors used benefit transfer to estimate the value of a statistical life in Brazil, based on an estimated value of a statistical life in the US equal to US$4,800,000 (1990) and income-adjusting (purchasing power parity) to Brazil (US$577,243 in 1999 values). Table 82 shows the mortality benefit estimates.

Table 82: Mortality values associated with the PROCONVE programme - São Paulo

	Avoided deaths		Benefit (US$ 1999)	
	0-2 years	> 64 years	0-2 years	> 64 years
NO2	1,420	----	819,685,516	----
PM10	----	798	----	460,640,170
SO2	----	-578	----	-333,646,640
CO	----	3,302	----	1,906,057,446
Totals	1,420	3,522	819,685,516	2,033,050,977

Source: Adapted from Pinheiro *et al.* (2004).

The total number of avoided deaths attributed to the PROCONVE programme in Sao Paulo was multiplied by our preferred estimates of the value of a statistical life and the corresponding estimates using 'non-yeah-saying' respondents, producing different estimates of the mortality benefit of the PROCONVE programme. Table 83 shows the mortality benefit estimates and the percentage variation of the benefit based on transferred estimates (Pinheiro *et al.* 2004) and the benefit figures using our estimates of the value of a statistical life, assuming that estimates based on original stated preference methods are preferable to benefit transfer estimates.

Table 83: Impact of using different mortality values associated with the PROCONVE programme in São Paulo

	VSL (US$)	Benefit valuation	Difference
Pinheiro *et al.* (2004)	577,243	2,852,736,493	---
Preferable estimate [(a)] – lower value	767,187	3,791,438,154	-24.8%
Preferable estimate – upper value	1,306,941	6,458,902,422	-55.8%
No 'yeah-say' – lower value	415,831	2,055,036,802	38.8%
No 'yeah-say' – upper value	489,752	2,420,354,384	17.9%

(a) Mean and median estimates of the WTP for a 5-in-1000 immediate risk reduction.

As can be seen in Table 83, the divergences between mortality benefit estimates can be significant. In this example, the observed variation in total benefit is the same variation observed in the value of a statistical life since no adjustments were undertaken in the value of a statistical life according to sub-groups of the affected population (e.g. different age groups).

The accuracy in estimating the health benefits, especially mortality benefits, of policies can be determinant in decision making when costs and benefits associated with the policy are of the same magnitude or similar to each other. This importance is decreased whether the costs and total benefits differ in order of magnitude, as it seems that it was the case of the PROCONVE programme in Brazil. Pinheiro *et al.* (2004) did not provide estimates of the implementation costs of the programme but it is unlikely that its costs have been measured in billions of dollars. In this case, inaccurate estimates of the health benefits would not have an impact in the decision about implementing the programme since the cost-benefit ratio is still lower than one (benefits higher than costs). However, if this inaccurate cost-benefit ratio of the PROCONVE programme had to be compared with the cost-benefit ratio of alternative policies (e.g. health or educational projects), the inaccurate benefit estimate could have been responsible for the rejection of the programme in favour of another project that presented a better cost-benefit ratio.

The PROCONVE programme analysis was ex-post, which means that no decision was made based on the results of a cost-benefit analysis. The impact of 'wrong' benefit estimates can be more significant in ex-ante analyses when decisions are made whether undertaking the policy or not. Our next case study is an example of an ex-ante analysis.

7.3.3. PITU – Integrated urban transport programme – Sao Paulo

Traffic jams are frequent in Sao Paulo during rush hours, contributing significantly to the worsening of air quality in the Sao Paulo metropolitan region. The economic and fuel loss due to traffic congestion is estimated at US$6.2 million a day (Omarsal and Ganton, 1997). Limited integration between the metro and suburban trains are also responsible for the traffic jams since it discourages rail-based trips in favour of trips by cars and buses. For example, in 1990 about 30 million trips a day were made in the metropolitan region of Sao Paulo (Table 84), 10 million of these were walking trips and the remaining 20 million trips consisted of cars (40%), buses (38%), metro (14%), and metropolitan train (6%,) (Omarsal and Ganton, 1997).

Table 84: Daily trip distribution in the Sao Paulo Metropolitan Region, 1990

Mode	Trips a day (million)	Per cent
Individual motorised transport		
Car	8.2	27
Motorcycle and other	0.2	1
Public transport		
Bus	7.8	25
Metro	2.8	9
Train	1.2	4
Other	0.2	1
Non-motorised transport (on foot)	10.0	33
Total	30.4	100

Source: Omarsal and Ganton, 1997

The Integrated Urban Transport Program – PITU – was conceived to plan and administer the urban transport sector in the metropolitan region of Sao Paulo. It consists of an investment (long-term) plan of urban transportation strategies. Environmental issues were among the concerns of the PITU programme. It comprises ongoing infrastructure projects aiming to increase integration of the metro and railway systems with the road transportation. Also, studies are under way for planning the future in a broader scenario – to the year 2020.

Pinheiro *et al.* (2004) presented results of the analysis of alternative air quality scenarios resulting from emissions projections to 2020 in Sao Paulo, as part of the Integrated Environmental Strategies (IES) project in Brazil[104]. The total implementation of the PITU programme comprised one of the scenarios studied. The authors obtained the energy and emission inventory for year 2000, the baseline year, including data and parameters regarding energy use, population, and economic activities. The analysis assumed population growth, increased mobility per capita and the share of public transportation, constant economic growth, improved income distribution and efficiency in energy use. Using air quality models that combine the emission inventory with meteorological data, the authors estimated ambient air quality concentrations under each scenario for years 2005, 2010, 2015, and 2020. Finally, the anticipated health impacts were estimated using locally derived dose-response functions for each mortality impact (total, cardiovascular and respiratory)/pollutant/scenario, as described before in the PROCONVE case study.

Table 85: Avoided mortality events attributed to air pollution exposure with full implementation of PITU in the metropolitan region of Sao Paulo (US$1000)

Event	Avoided deaths	Lower bound valuation	Upper bound valuation
CRM-PM_{10}	116	66,960	92,830
CRM-SO_2	10	5,772	8,003
CRM-CO	175	101,018	140,045
ETM-PM_{10}	1,625	938,518	1,301,110
ETM-SO_2	162	93,407	129,495
ETM-CO	1,134	655,041	908,113
ERM-PM_{10}	459	264,348	366,477
ERM-SO_2	23	13,123	18,193
ECVDM-SO_2	44	24,995	34,652
ECVDM-CO	435	251,173	348,212

Notes: CRM = child respiratory mortality; ETM = elderly total mortality; ERM = elderly respiratory mortality; ECVDM = elderly cardiovascular mortality.
Source: Adapted from Pinheiro *et al.*, (2004).

Table 85 shows the results for the scenario involving the full implementation of the PITU programme in Sao Paulo. The avoided deaths from air pollution related effects in the metropolitan region of Sào Paulo from 2000 to 2020 were estimated to equal 1,800 (the sum of maximum values of child mortality and total elderly mortality). As can be seen in Table 85, PM_{10} presented the strongest association with respiratory mortality among children and among the elderly, and the elderly total mortality, whereas for cardiovascular disease CO was associated with the highest mortality among the elderly. The economic valuation used transferred values of a statistical life from the US (US$577,243) and Europe – ExternE Project (US$800,258). Table 86 shows the economic valuation of the mortality impact associated with the PITU programme using the estimates of the value of a statistical life generated in the contingent valuation study undertaken in Sao Paulo.

[104] http://www.epa.gov/ies/brazil.htm

Table 86: Impact of using different mortality values associated with the full implementation of the PITU programme in São Paulo (2000-2020)

		VSL (US$)	Benefit valuation (US$ 1000)
CRM-CO	Pinheiro *et al.* (2004)	577,243 – 800,258	101,018 – 140,045
	Preferable estimate [(a)]	767,187 - 1,306,941	134,258 – 228,715 (-33.6%)
	Excluding 'yeah-saying'	415,831 – 489,752	72,770 – 85,707 (52.1%)
$ETM\text{-}PM_{10}$	Pinheiro *et al.* (2004)	577,243 – 800,258	938,518 – 1,301,110
	Preferable estimate [(a)]	767,187 - 1,306,941	1,246,679 – 2,123,779 (-33.6%)
	Excluding 'yeah-saying'	415,831 – 489,752	675,725 – 795,847 (52.2%)

(a) Mean and median estimates of the WTP for a 5-in-1000 immediate risk reduction.

As can be seen in Table 86, the difference on total benefit estimate can be significant. When considering the mid-point of the intervals, the total mortality benefit estimate reported by Pinheiro *et al.* (2004) was 33.6% lower than the corresponding figure using our preferred set of estimates of the value of a statistical life. On the other hand, the estimates used by Pinheiro *et al.* (2004) in their analysis are 52.1% higher than the estimates obtained using the sample where the 'yeah-saying' respondents are excluded.

Again, Pinheiro *et al.* (2004) did not provide estimates of the costs involved in the analysed projects. In order to provide some basis of comparison, Table 87 shows the estimated costs of past and ongoing projects in the Brazilian urban transport sector. There were no details on which projects comprise the costs associated with the PITU programme, the smallest figure among the projects in Table 87.

Table 87: World Bank projects in the Brazilian urban transport sector

Status	Project	Cost [(a)]
Closed Projects	Sao Paulo Metro Transport Decentralization (1992)	281.0
	Urban Transport Rail II (1980)	312.8
	Third Urban Transport (1981)	257.0
	Fourth Urban Transport (1987)	468.2
Ongoing Projects	Sao Paulo Integrated Urban Transport – PITU (1998)	95.1
	Rio Transport Decentralization (1993)	272.0
	Rio Mass Transit (1997)	373.0
	Belo Horizonte Metropolitan Transport Decentralization (1995)	197.3
	Recife Metropolitan Transport Decentralization (1995)	203.8
	Salvador Urban Transport (1999)	308.0

(a) US$ millions
Source: Adapted from Kojima and Lovei (2001)

7.4. Conclusions

This Chapter aimed to discuss the relevance of the empirical results obtained in this study in terms of policy analysis in Brazil by investigating alternative approaches to undertake policy analysis in the absence of estimates of the value of a statistical life originally generated in Brazil. The alternative approaches that can provide proxies of the value of a statistical life (year) in Brazil and that were investigated were the studies of cost-effectiveness of medical interventions, some GDP-based approaches, and the benefit transfer methods. In every case the available estimates were compared with our results and two study cases highlighted potential divergences among the results when different estimates of the value of a statistical life are used.

A limited number of cost-effectiveness studies in Brazil did provide estimates of cost per life saved, but the available estimates could not be regarded as fully comparable with willingness-to-pay measures, each of them failing to present some of the desired characteristics of cost-effectiveness ratios in order to represent willingness to pay. The cost-effectiveness results can, at best, be considered as a lower bound for the willingness-to-pay estimates. Benefit transfer methods were tested using the UK results of an identical contingent valuation survey, which minimised differences in the results in terms of study design and statistical methods. The transferred estimates presented average transfer errors equal to 69% (full sample) and 63% when the same analysis is undertaken excluding the cooperative respondents (No 'yeah-say' respondents).

The case studies aimed to compare the results of two recent analyses in Brazil that relied on benefit transfer methods with the results using the estimates provided by this study, given that it is understood that the accuracy in (ex-ante) estimation of the mortality benefits of certain policies can be a determinant of the decision to undertake or not the specified policies. The divergences in measuring the mortality benefits of the specific projects were significant when our values of a statistical life were used, ranging between 24% and 55% in the case of PROCONVE and between 33% and 55% in the PITU case study. The divergence between transferred estimates of the value of a statistical life (or other similar proxy such as the cost per life saved) and locally derived estimates using original studies can be substantially increased when the number of fatalities associated with the analysed policies increase. It can be concluded that the variance between 'true' values of a statistical life and their proxies can be decisive in rejecting a 'good' policy and/or accepting a 'bad' policy, which reinforces the need of original stated preference studies and, by extension, the relevance of this study for policy making in Brazil in the context of air pollution.

8. Conclusion and discussion

Epidemiologic studies suggest that short-term and long-term exposure to different levels of air pollutants are positively associated with various health effects, including mortality. The adverse health effects of air pollution are currently widely accepted among researchers. Recent studies developed in Brazil associating air pollution with mortality trends confirm that mortality risks increase when pollutant levels increase in Sao Paulo. In order to undertake policy analysis and formulate policies that aim to reduce air pollution, policy makers should know how much the society evaluates the mortality risk reduction associated with the proposed policies. This study has aimed to estimate such benefit in Sao Paulo and provided estimates of the value of a statistical life in Brazil. In addition, the effects of respondents' age and health status on the willingness-to-pay estimates were investigated, along with the willingness to pay for a risk reduction happening in the future.

This study has explored the different perspectives to establish appropriate economic values for changes in risk of death and reviewed the main characteristics, advantages and disadvantages of each approach and valuation method. It has used the willingness-to-pay approach and the contingent valuation method to elicit the population's willingness to pay for small mortality risk reductions. The study included a contingent valuation survey undertaken in Sao Paulo between October 2002 (pilot survey) and March 2003 (final survey) that used a survey instrument (questionnaire) especially designed to estimate the willingness to pay for reducing an individual's risk of death (Krupnick *et al.*, 1998, 1999). The survey instrument has been adapted to the Brazilian context, allowing the estimation of individuals' willingness to pay for different reductions in probabilities of death. The survey has targeted individuals resident in Sao Paulo, aged 40-75 (percentages per age intervals reflecting the city population profile), and belonging to A, B and C social classes – rich and middle class.

The results suggest that the value of a statistical life in Brazil ranges between US$0.77 and 6.1 million. The preferred estimates for policy analyses in Brazil range between US$0.77 and US$1.31 million. The corresponding value of a statistical life year ranged between US$ 61,392 and US$ 159,456. If these numbers were compared with similar estimates in other developed countries it seems that these figures are higher than would be expected for a middle-income country like Brazil. For example, the international literature review of empirical studies, focused on the main willingness-to-pay-based methods used to estimate the value of a statistical life, presented values of a statistical life ranging between US$0.5 and US$20.8 million in the US based on a meta-analysis study of 'compensating-wage' studies. The review of contingent valuation studies using the Krupnick *et al.* (1998, 1999) methodology resulted in estimates ranging between US$0.5 (Canada) and US$7.6 (Italy) million. Averting behaviour studies also presented a wide range of estimates – US$0.77 and US$4.3 million, and meta-analyses of studies estimating the value of a statistical life ranged between US$1.5 and US$5.6 million. From the literature review of international values of a statistical life it can be concluded that, although these estimates can be very sensitive to the valuation method used, to the dataset used, to the assumptions and statistical methods used in the valuation exercise, the Brazilian figures are not so different from those observed in developed countries. Given the income differentials between Brazil and industrialised countries, it would be expected that our estimates of the value of a statistical life should be lower than those estimates in the developed world, even observing that other studies in developing countries (e.g. Chesnut *et al.*, 1997) found that health can be seen as a basic necessity so that individuals with lower incomes may be willing to pay a higher share of their income to protect their health.

The best explanation for the unexpected high results obtained in Brazil refers to the 'cooperative' or 'yeah-saying' behaviour observed in part of the respondents since a bias might have been introduced by the use of an incentive payment to each respondent for his or her participation in the survey. Several comments made by respondents to the effect that they were keen to take part in the survey and other such surveys provided the evidence of the 'yeah-say' bias. It is possible that respondents might have tried to be 'cooperative' or helpful by saying 'yes' to every question. This 'yeah-saying' behaviour has been observed in several contingent valuation studies using the dichotomous choice format of the willingness-to-pay questions (e.g. Ready *et al.*, 1986).

Estimates using a sub-sample where the 'yeah-say' respondents were excluded showed that the willingness-to-pay results are much smaller than those using the full sample, implying a value of a statistical life equal to US$0.49 million (mean) and US$0.41 million (median) for a 5-in-1000 immediate risk reduction (full range between US$0.41 and US$2.41 million). The value of a statistical life year ranged between US$34,729 and US$62,944. The mean value of a statistical life estimate, for example, corresponds to approximately half the estimate for Canada, one-fifth of the US and the UK figures, and almost one-sixth of the Italian result. The Brazilian 'no yeah-say' figures are, therefore, more in line with the results that would be expected from mortality risk valuation exercises undertaken in developing country.

However, these results must be taken carefully since it was not possible to distinguish genuine 'yes' responses (those obtained after an implicit utility maximising process constrained by income) from 'yeah-say' respondents. As a result, it cannot be claimed with certainty that the 'no yeah-say' figures are more representative of the Brazilian society's preferences than those using the full sample, although the comparison of results between developed and developing countries may suggest it. The exclusion of possible 'yeah-saying' respondents aimed to highlight the impact that this type of bias can have on the value of a statistical life. This caveat can be regarded as a possible improvement for future contingent valuation studies in Brazil and other developing countries, in order to test whether this behaviour can be generalised and regarded as a typical middle and low-income country phenomenon.

No age effect on the willingness-to-pay estimates for small risk reductions in Brazil could have been identified from the samples and sub-samples available in this study. The coefficients of the age variable in different models explaining the willingness-to-pay responses were always not statistically significant at the usual levels. Mean and median willingness to pay for different age groups were estimated using the constant-only approach, which in theory is not affected by regressors, presented no consistent pattern between samples and sub-samples. The result reinforces the conclusion that no significant age effect exists in the Brazilian estimates, which is a similar result than those observed in the US, France and the UK.

No significant cancer, respiratory or cardiovascular disease effect on willingness-to-pay responses could be identified in the Brazilian results given the lack of statistical significance of the coefficients in several regressions. Also, hospital admission and emergency-room visit had no significant effect on willingness to pay. A relevant result regards the statistically significant effect of the physical function on the willingness to pay for mortality risk reduction; a consistent result observed in all sub-samples both using the final and the pilot sample. The positive sign of the parameter suggests that the healthier the respondent feels (physically) the more this respondent would like to pay for a reduction in his or her risk of dying. The positive health status effect on willingness to pay was similar to the impact observed in the US and European studies, although for different health aspects.

Willingness-to-pay estimates for a reduction in risk of dying that happens in the future were not consistent with theory when some sub-samples were used, that is, results were not smaller than the corresponding willingness to pay for a risk reduction of the same magnitude that occurs immediately. However, when individuals who inconsistently answered the willingness-to-pay questions were removed from the sample the results were in accordance with theory. It has been shown that the 'cooperative behaviour' demonstrated by a significant share of respondents has had an impact on the willingness to pay for a risk reduction that happens in the future. When the 'yeah-say' respondents were removed from the sample ('no yeah-say' sample) all the results were in accordance with theory.

The relevance of the empirical results obtained in this study in terms of policy analysis in Brazil was investigated by examining alternative approaches to undertake policy analysis in the absence of estimates of the value of a statistical life originally generated using the established valuation methods. These alternative approaches investigated were the cost-effectiveness of medical interventions, some GDP-based approaches, and the benefit transfer method. Few appropriate cost-effectiveness studies were available in Brazil and the provided estimates could not be regarded as fully comparable with willingness-to-pay measures. Benefit transfer methods, which are the most used techniques in developing countries as an alternative to undertaken proper valuation exercises, presented average transfer errors equal to 69% (full sample) and 63% when the same analysis is undertaken excluding the cooperative respondents. The difference is significant if it is considered that similar exercise undertaken within European countries presented an average transfer error equal to 38% (Ready *et al.*, 2004). No benefit transfer method could have been identified as preferable in case an original valuation study would not be possible in Brazil.

Two recent Brazilian case studies compared the results obtained by using benefit transfer methods with the results using the estimates obtained in the contingent valuation exercise undertaken in this study, highlighting potential divergences arising when different estimates – transferred and locally derived estimates – of the value of a statistical life are used. The divergences in measuring the mortality benefits of the specific projects were significant when our values of a statistical life were used, ranging between 24% and 55% in one case study and between 33% and 55% in another. It suggests that the benefit transfer errors of the value of a statistical life can have a substantial impact in the cost-benefit analysis if the number of fatalities associated with the analysed policy is high. Given that the mortality effects of policies that aim to reduce air pollution correspond to a significant share of the total effects, the impact of benefit transfer errors can result in inaccurate policy analysis and mistaken decisions whether implementing or not these policies.

In summary, the main contribution of this research to the literature relates to the usefulness of its findings for future designing and implementation of valuation exercises undertaken in Brazil and other developing countries in the context of mortality risks associated with air pollution. First, it seems that paying respondents in cash as an incentive for their participation in the survey can be associated with their 'cooperative' behaviour. Further research is necessary to formally test the existence of such bias in Brazil and other developing countries, and determine better survey designs that can minimise the possibility of 'yeah-saying' behaviour among the respondents. Second, it seems that it was rather difficult for respondents in Sao Paulo to understand the concept of probability and distinguish between different small risk reductions given the high percentage of wrong answers to the probability tests undertaken in the survey. In the future other procedures must be tested in order to better explain and test the concept of risks, especially for the share of the population with lower education levels. Third, it is important to understand why willingness-to-pay values for different risk levels do not observe the desirable characteristic of non-strict proportionality between risk sizes and, consequently, not behaving consistently with expectations. It may be related either to the misunderstanding of the concept of risk reduction or to the 'yeah-saying' behaviour in Brazil. However, it seems that this is a wider problem since the lack of proportionality between willingness-to-pay estimates has also been observed in all contingent valuation studies in the context of air pollution in developed countries.

Finally, it is pertinent to discuss how the literature on mortality risk valuation in the context of air pollution has moved on since the beginning of this research and in which direction it possibly will go. At the beginning of this research (2001), the methodology developed by Krupnick *et al.* (1999, 2001) and used in this research could be regarded as the state-of-the-art methodology to estimate individuals' willingness to pay for a mortality risk reduction similar to those observed in the air pollution context. The authors aimed to overcome problems associated with using estimates of the value of a statistical life generated in a context other than the air pollution context, such as transport fatalities and work-place accidents. Examples of these problems are the average age of the mainly affected population in different contexts, the risk size experienced in those contexts and the latency problem associated with some pollutants. However, as technology developed and recent epidemiologic studies provided a better understanding of the physical effect of air pollution on the human health, an important discussion has dominated the literature: the usefulness of the value of a statistical life as the most appropriate metric for evaluating deaths associated with exposure to air pollutants when compared with the more recent concept of the value of a statistical life year (VSLY). This discussion has motivated a number of seminars, expert meetings[105] and studies to elaborate recommendations for policy analysis in the context of air pollution[106].

It seems that there is a trend in the recent literature to accept the value of a statistical life year as the most important metric for policy making in the context of air pollution, although there is still no consensus among researchers, especially between European and North American researchers. The main argument underlying this discussion is the claim that the relevant health impacts that can be associated with air pollution increase (the chronic effects) are primarily expressed in changes in life expectancy or years of life lost instead of the number of deaths. In addition, the acute or short-term mortality effects of air pollution are deaths of the elderly, which have fewer life years lost at the moment of their deaths than younger individuals. In this sense, the value of a statistical life year is claimed to be more appropriate for policy analysis in the context of air pollution than the value of a statistical life, a statistic that refers to all individuals in the society, independently of age groups.

However, as shown in the empirical literature review, most of the values of a statistical life year available in the literature have been derived from existing estimates of the value of a statistical life. Alternatively, as undertaken in this study, these estimates have been derived from respondents' willingness-to-pay values for a small risk reduction, which is different from asking respondents to explicitly state their willingness to pay for an increase in their life expectancy. It seems that future research on mortality in the context of air pollution will go in the direction of an increasing number of studies investigating the value of a statistical life year directly using stated preference methods.

[105] For example, the UK Health Valuation Workshop held by DEFRA in June 2004.
[106] E.g. the UK government's Interdepartmental Group on Costs and Benefits (IGCB) report on the valuation of health benefits associated with reductions in air pollution (2004).

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10. Annexes

10.1. General structure of the questionnaire

- Initial comments about the survey;
- Respondent's age and gender;
- Occurrence of cancer, cardiac and respiratory diseases in the respondent's family and his or her own;
- Illustrates the concept of probabilities;
- Presents baseline risks per age and gender;
- Examples of life-saving activities and associated costs;
- Probability tests of comprehension;
- Willingness-to-pay questions:
    - WTP for a 5-in-1000 risk reduction in the next ten years, follow-up question and open-ended question to elicit the maximum WTP for the risk reduction;
    - WTP for a 1-in-1000 risk reduction in the next ten years, follow-up question and open-ended question to elicit the maximum WTP for the risk reduction;
    - WTP for a 5-in-1000 risk reduction in the future, follow-up question and open-ended question to elicit the maximum WTP for the risk reduction;
- Debriefing questions of the questionnaire and the good being valued;
- SF-36 questions (physical and mental health status);
- Socio-economic questions (e.g. income, marital status, education);
- Confirmation or update of WTP values.

10.2. T-tests of equality of mean values between pilot and final samples

. use c:\MortalityBrazil\Pooleddata\Pooled592.dta;

. ttest sexe, by(sample);   /* Gender: 1=man 2=woman */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |     283    1.551237    .0296178    .4982489    1.492937    1.609537
   pilot |     309    1.556634    .0283068     .497588    1.500935    1.612333
---------+--------------------------------------------------------------------
combined |     592    1.554054    .0204467    .4974899    1.513897    1.594211
---------+--------------------------------------------------------------------
    diff |            -.0053976     .040967              -.0858564    .0750613
------------------------------------------------------------------------------
Degrees of freedom: 590
                 Ho: mean(final) - mean(pilot) = diff = 0
     Ha: diff < 0               Ha: diff ~= 0              Ha: diff > 0
       t =  -0.1318                t =  -0.1318              t =  -0.1318
   P < t =   0.4476          P > |t| =   0.8952          P > t =   0.5524
```

. ttest age, by(sample);   /* Age of respondent */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |     283    56.02827    .5624405    9.461713    54.92115    57.13538
   pilot |     309    57.33981    .5863732     10.3075      56.186    58.49361
---------+--------------------------------------------------------------------
combined |     592    56.71284    .4079373    9.925542    55.91165    57.51402
---------+--------------------------------------------------------------------
    diff |            -1.311537    .8155689              -2.913309    .2902342
------------------------------------------------------------------------------
Degrees of freedom: 590
                 Ho: mean(final) - mean(pilot) = diff = 0
     Ha: diff < 0               Ha: diff ~= 0              Ha: diff > 0
       t =  -1.6081                t =  -1.6081              t =  -1.6081
```

```
P < t = 0.0542        P > |t| = 0.1083        P > t = 0.9458
```

. ttest educ, by(sample);   /* Years of education */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |   Obs      Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |   283   7.64311    .2480648    4.173096    7.154816    8.131403
   pilot |   309   9.252427   .2593259    4.558534    8.742153    9.762702
---------+--------------------------------------------------------------------
combined |   592   8.483108    .18282     4.448204    8.124052    8.842164
---------+--------------------------------------------------------------------
    diff |        -1.609318   .3602616               -2.316869   -.9017664
------------------------------------------------------------------------------
Degrees of freedom: 590
            Ho: mean(final) - mean(pilot) = diff = 0
   Ha: diff < 0            Ha: diff ~= 0           Ha: diff > 0
    t = -4.4671             t = -4.4671             t = -4.4671
 P < t = 0.0000         P > |t| = 0.0000         P > t = 1.0000
```

. ttest incomei, by(sample); /* Individual income */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |   Obs      Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |   283   844.8174   67.77983    1140.233    711.3988    978.236
   pilot |   309   1902.697   135.9523    2389.824    1635.184    2170.21
---------+--------------------------------------------------------------------
combined |   592   1396.988   80.92062    1968.884    1238.061    1555.915
---------+--------------------------------------------------------------------
    diff |        -1057.879   156.1758               -1364.608   -751.1512
------------------------------------------------------------------------------
Degrees of freedom: 590
            Ho: mean(final) - mean(pilot) = diff = 0
   Ha: diff < 0            Ha: diff ~= 0           Ha: diff > 0
    t = -6.7736             t = -6.7736             t = -6.7736
 P < t = 0.0000         P > |t| = 0.0000         P > t = 1.0000
```

. ttest fumeur, by(sample); /* If respondent smokes: 1=yes 2=no */;

```
Two-sample t test with equal variances
```

```
------------------------------------------------------------------------------
  Group |   Obs      Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
  final |   283   1.706714   .0271108    .456075   1.653348    1.760079
  pilot |   309   1.805825   .0225394   .3962057   1.761475    1.850176
---------+--------------------------------------------------------------------
combined |   592   1.758446   .0176066   .4283873   1.723867    1.793025
---------+--------------------------------------------------------------------
   diff |        -.0991115   .0350403              -.1679304   -.0302925
------------------------------------------------------------------------------
Degrees of freedom: 590
            Ho: mean(final) - mean(pilot) = diff = 0
   Ha: diff < 0          Ha: diff ~= 0          Ha: diff > 0
     t = -2.8285           t = -2.8285           t = -2.8285
  P < t =  0.0024       P > |t| =  0.0048       P > t =  0.9976
```

. ttest religion, by(sample); /* Religion: 1=very religious...5=not at all */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
  Group |   Obs      Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
  final |   283   1.971731   .0541228   .9104863   1.865196    2.078267
  pilot |   309   2.071197   .0451992   .7945301   1.982259    2.160136
---------+--------------------------------------------------------------------
combined |   592   2.023649   .0350439   .8526548   1.954823    2.092474
---------+--------------------------------------------------------------------
   diff |        -.099466   .0700954              -.2371328    .0382009
------------------------------------------------------------------------------
Degrees of freedom: 590
            Ho: mean(final) - mean(pilot) = diff = 0
   Ha: diff < 0          Ha: diff ~= 0          Ha: diff > 0
     t = -1.4190           t = -1.4190           t = -1.4190
  P < t =  0.0782       P > |t| =  0.1564       P > t =  0.9218
```

. ttest mutuelle, by(sample);   /* Health insurance: 1=yes 2=no */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
  Group |   Obs      Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
  final |   283   1.561837   .029546    .4970403   1.503679    1.619996
```

```
   pilot |    309    1.33657   .0269253   .4733027   1.283589    1.38955
---------+--------------------------------------------------------------------
combined |    592   1.444257    .020439   .4973032   1.404115   1.484399
---------+--------------------------------------------------------------------
    diff |          .2252679   .0398883              .1469276   .3036082
------------------------------------------------------------------------------
Degrees of freedom: 590

              Ho: mean(final) - mean(pilot) = diff = 0

    Ha: diff < 0           Ha: diff ~= 0           Ha: diff > 0
     t =   5.6475            t =   5.6475           t =   5.6475
  P < t =   1.0000        P > |t| =   0.0000       P > t =   0.0000
```

. ttest marital, by(sample);   /* Marital status: 1=married 0=otherwise */;

Two-sample t test with equal variances

```
------------------------------------------------------------------------------
   Group |    Obs       Mean   Std. Err.  Std. Dev.  [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |    283   .6537102   .0283327   .4766297   .5979398   .7094807
   pilot |    309   .6569579     .02705   .4754954   .6037318   .7101841
---------+--------------------------------------------------------------------
combined |    592   .6554054   .0195486   .4756378   .6170122   .6937986
---------+--------------------------------------------------------------------
    diff |         -.0032477   .0391679             -.0801731   .0736777
------------------------------------------------------------------------------
Degrees of freedom: 590

              Ho: mean(final) - mean(pilot) = diff = 0

    Ha: diff < 0           Ha: diff ~= 0           Ha: diff > 0
     t =  -0.0829            t =  -0.0829           t =  -0.0829
  P < t =   0.4670        P > |t| =   0.9339       P > t =   0.5330
```

. ttest enfants, by(sample);   /* Kids: 1=yes 2=no */;

Two-sample t test with equal variances

```
------------------------------------------------------------------------------
   Group |    Obs       Mean   Std. Err.  Std. Dev.  [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |    283   1.102473   .0180595   .3038072   1.066925   1.138022
   pilot |    309   1.067961   .0143408   .2520875   1.039743   1.096179
---------+--------------------------------------------------------------------
combined |    592   1.084459   .0114385   .2783108   1.061994   1.106925
---------+--------------------------------------------------------------------
```

```
  diff |       .0345123   .0228744              -.0104129   .0794375
------------------------------------------------------------------------------
Degrees of freedom: 590
             Ho: mean(final) - mean(pilot) = diff = 0
   Ha: diff < 0           Ha: diff ~= 0           Ha: diff > 0
     t =  1.5088            t =  1.5088            t =  1.5088
 P < t =  0.9341        P > |t| =  0.1319        P > t =  0.0659
```

. ttest etatsant, by(sample); /* Subjective health status 1=good...5=bad */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
  Group |   Obs      Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
  final |   283   1.819788   .0505352   .8501339   1.720314   1.919262
  pilot |   309   1.831715   .0459846   .8083356   1.741231   1.922199
---------+--------------------------------------------------------------------
combined |   592   1.826014   .0340264   .827897   1.759186   1.892841
---------+--------------------------------------------------------------------
  diff |      -.0119272   .0681744              -.1458212   .1219668
------------------------------------------------------------------------------
Degrees of freedom: 590
             Ho: mean(final) - mean(pilot) = diff = 0
   Ha: diff < 0           Ha: diff ~= 0           Ha: diff > 0
     t = -0.1750            t = -0.1750            t = -0.1750
 P < t =  0.4306        P > |t| =  0.8612        P > t =  0.5694
```

. ttest cancerh, by(sample); /* History of cancer: 1=yes 0=no */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
  Group |   Obs      Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
  final |   283   .3286219   .027971   .4705443   .2735636   .3836803
  pilot |   309   .3559871   .0272828   .479588   .3023028   .4096713
---------+--------------------------------------------------------------------
combined |   592   .3429054   .0195257   .4750816   .3045571   .3812537
---------+--------------------------------------------------------------------
  diff |      -.0273651   .0391061              -.1041692   .0494389
------------------------------------------------------------------------------
Degrees of freedom: 590
             Ho: mean(final) - mean(pilot) = diff = 0
```

```
  Ha: diff < 0          Ha: diff ~= 0          Ha: diff > 0
    t =  -0.6998          t =  -0.6998          t =  -0.6998
 P < t =   0.2422      P > |t| =   0.4843      P > t =   0.7578
```

. ttest respirat, by(sample); /* Respiratory diseases: 1=yes 0=no */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |     283    .3180212    .0277325    .4665328    .2634322    .3726102
   pilot |     309    .3430421      .02705    .4754954    .2898159    .3962682
---------+--------------------------------------------------------------------
combined |     592    .3310811     .019358    .4710001    .2930623    .3690999
---------+--------------------------------------------------------------------
    diff |           -.0250209    .0387725               -.1011698    .0511281
------------------------------------------------------------------------------
Degrees of freedom: 590
             Ho: mean(final) - mean(pilot) = diff = 0
  Ha: diff < 0          Ha: diff ~= 0          Ha: diff > 0
    t =  -0.6453          t =  -0.6453          t =  -0.6453
 P < t =   0.2595      P > |t| =   0.5190      P > t =   0.7405
```

. ttest cardiac, by(sample); /* Cardiovascular diseases: 1=yes 0=no */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |     283    .6360424    .0286513     .481989    .5796449    .6924399
   pilot |     309    .6245955    .0275914    .4850126     .570304     .678887
---------+--------------------------------------------------------------------
combined |     592    .6300676    .0198592    .4831944    .5910644    .6690707
---------+--------------------------------------------------------------------
    diff |            .0114469    .0397876               -.0666956    .0895895
------------------------------------------------------------------------------
Degrees of freedom: 590
             Ho: mean(final) - mean(pilot) = diff = 0
  Ha: diff < 0          Ha: diff ~= 0          Ha: diff > 0
    t =   0.2877          t =   0.2877          t =   0.2877
 P < t =   0.6132      P > |t| =   0.7737      P > t =   0.3868
```

. ttest erhosp, by(sample); /* Emergency room or hospital admission */;

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
final	283	.204947	.0240378	.404378	.1576308	.2522632
pilot	309	.1585761	.0208138	.3658728	.1176209	.1995312
combined	592	.1807432	.0158288	.3851307	.1496558	.2118307
diff		.0463709	.0316575		-.0158041	.108546

Degrees of freedom: 590

Ho: mean(final) - mean(pilot) = diff = 0

Ha: diff < 0	Ha: diff ~= 0	Ha: diff > 0
t = 1.4648	t = 1.4648	t = 1.4648
P < t = 0.9282	P > |t| = 0.1435	P > t = 0.0718

. ttest agedcs, by(sample); /* Subjective age of death: 1=sooner...9=later */;

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
final	283	5.491166	.1138663	1.915528	5.26703	5.715302
pilot	309	5.601942	.0990667	1.741434	5.407009	5.796875
combined	592	5.548986	.0750486	1.82601	5.401592	5.696381
diff		-.1107757	.1503002		-.4059642	.1844128

Degrees of freedom: 590

Ho: mean(final) - mean(pilot) = diff = 0

Ha: diff < 0	Ha: diff ~= 0	Ha: diff > 0
t = -0.7370	t = -0.7370	t = -0.7370
P < t = 0.2307	P > |t| = 0.4614	P > t = 0.7693

. ttest comprhen, by(sample); /* Subjective comprehension of probability */;

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
final	283	4	.0764144	1.285489	3.849585	4.150415
pilot	309	4.236246	.0641582	1.127798	4.110002	4.36249
combined	592	4.123311	.0497512	1.2105	4.0256	4.221022
diff		-.236246	.0992073		-.4310884	-.0414035

Degrees of freedom: 590

Ho: mean(final) - mean(pilot) = diff = 0

Ha: diff < 0	Ha: diff ~= 0	Ha: diff > 0
t = -2.3813	t = -2.3813	t = -2.3813
P < t = 0.0088	P > |t| = 0.0176	P > t = 0.9912

. ttest croyance, by(sample); /* If accepted baseline risk as his/her own */;

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
final	283	1.222615	.0247725	.4167387	1.173852	1.271377
pilot	309	1.187702	.0222493	.3911076	1.143922	1.231482
combined	592	1.204392	.0165878	.4035976	1.171814	1.23697
diff		.0349126	.0332046		-.030301	.1001262

Degrees of freedom: 590

Ho: mean(final) - mean(pilot) = diff = 0

Ha: diff < 0	Ha: diff ~= 0	Ha: diff > 0
t = 1.0514	t = 1.0514	t = 1.0514
P < t = 0.8533	P > |t| = 0.2935	P > t = 0.1467

. ttest fdoutes, by(sample); /* Doubts about efficacy of proposed good */;

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
final	283	.3639576	.0286513	.481989	.3075601	.4203551
pilot	309	.3754045	.0275914	.4850126	.321113	.429696

```
combined |   592   .3699324   .0198592   .4831944   .3309293   .4089356
---------+--------------------------------------------------------------------
    diff |        -.0114469   .0397876             -.0895895   .0666956
------------------------------------------------------------------------------
Degrees of freedom: 590
              Ho: mean(final) - mean(pilot) = diff = 0
   Ha: diff < 0           Ha: diff ~= 0           Ha: diff > 0
    t =  -0.2877            t =  -0.2877            t =  -0.2877
  P < t =   0.3868        P > |t| =   0.7737       P > t =   0.6132
```

. ttest feffets, by(sample);   /* If considered side effects */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |   Obs       Mean   Std. Err.  Std. Dev.  [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |   283    .360424   .0285909    .480974   .3041453   .4167028
   pilot |   309   .3398058   .0269883   .4744114    .286701   .3929106
---------+--------------------------------------------------------------------
combined |   592   .3496622   .0196155   .4772665   .3111375   .3881868
---------+--------------------------------------------------------------------
    diff |         .0206182   .0392931             -.0565531   .0977895
------------------------------------------------------------------------------
Degrees of freedom: 590
              Ho: mean(final) - mean(pilot) = diff = 0
   Ha: diff < 0           Ha: diff ~= 0           Ha: diff > 0
    t =   0.5247            t =   0.5247            t =   0.5247
  P < t =   0.7000        P > |t| =   0.6000       P > t =   0.3000
```

. ttest ffinance, by(sample); /* If considered his/her finances */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |   Obs       Mean   Std. Err.  Std. Dev.  [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |   283   .7137809   .0269158   .4527937   .6607996   .7667623
   pilot |   309   .7572816   .0244289   .4294217   .7092128   .8053503
---------+--------------------------------------------------------------------
combined |   592   .7364865   .0181213    .440911   .7008964   .7720765
---------+--------------------------------------------------------------------
    diff |        -.0435006   .0362642             -.1147233    .027722
------------------------------------------------------------------------------
```

Degrees of freedom: 590

Ho: mean(final) - mean(pilot) = diff = 0

Ha: diff < 0	Ha: diff ~= 0	Ha: diff > 0
t = -1.1995	t = -1.1995	t = -1.1995
P < t = 0.1154	P > |t| = 0.2308	P > t = 0.8846

. ttest fautres, by(sample); /* If benefited other members of family */;

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
final	283	.4840989	.0297595	.5006324	.42552	.5426779
pilot	309	.4822006	.0284721	.5004936	.4261762	.5382251
combined	592	.4831081	.0205555	.5001372	.4427374	.5234788
diff		.0018983	.0411855		-.0789898	.0827863

Degrees of freedom: 590

Ho: mean(final) - mean(pilot) = diff = 0

Ha: diff < 0	Ha: diff ~= 0	Ha: diff > 0
t = 0.0461	t = 0.0461	t = 0.0461
P < t = 0.5184	P > |t| = 0.9633	P > t = 0.4816

. ttest mhs, by(sample); /* Mental health score: 0-100 */;

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
final	283	65.85159	1.042837	17.54324	63.79886	67.90432
pilot	309	67.81877	1.0592	18.61903	65.73459	69.90295
combined	592	66.87838	.7448994	18.12418	65.41541	68.34135
diff		-1.96718	1.490302		-4.894122	.9597621

Degrees of freedom: 590

Ho: mean(final) - mean(pilot) = diff = 0

Ha: diff < 0	Ha: diff ~= 0	Ha: diff > 0
t = -1.3200	t = -1.3200	t = -1.3200

P < t = 0.0937 P > |t| = 0.1874 P > t = 0.9063

. ttest pfs, by(sample); /* Physical function score: 0-100 */;

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
final	283	72.24382	1.629668	27.41526	69.03596	75.45167
pilot	309	78.07443	1.462016	25.6999	75.19763	80.95124
combined	592	75.28716	1.096169	26.67093	73.1343	77.44002
diff		-5.830617	2.183157		-10.11832	-1.542913

Degrees of freedom: 590

Ho: mean(final) - mean(pilot) = diff = 0

Ha: diff < 0	Ha: diff ~= 0	Ha: diff > 0
t = -2.6707	t = -2.6707	t = -2.6707
P < t = 0.0039	P > |t| = 0.0078	P > t = 0.9961

. ttest rps, by(sample); /* Role limitation physical score: 0-100 */;

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
final	283	77.0318	2.198421	36.98316	72.7044	81.3592
pilot	309	81.39159	1.99951	35.14818	77.45716	85.32601
combined	592	79.30743	1.482563	36.07231	76.3957	82.21917
diff		-4.359784	2.965076		-10.18317	1.463604

Degrees of freedom: 590

Ho: mean(final) - mean(pilot) = diff = 0

Ha: diff < 0	Ha: diff ~= 0	Ha: diff > 0
t = -1.4704	t = -1.4704	t = -1.4704
P < t = 0.0710	P > |t| = 0.1420	P > t = 0.9290

. ttest ps, by(sample); /* Pain score: 0-100 */;

Two-sample t test with equal variances

```
------------------------------------------------------------------------------
  Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |     283    82.29289    1.193155    20.07198    79.94427    84.64151
   pilot |     309    83.85473    1.126675    19.80514    81.63777    86.07168
---------+--------------------------------------------------------------------
combined |     592    83.10811     .819182    19.93156    81.49925    84.71697
---------+--------------------------------------------------------------------
    diff |           -1.561835    1.640076               -4.782932    1.659262
------------------------------------------------------------------------------
Degrees of freedom: 590
                 Ho: mean(final) - mean(pilot) = diff = 0
     Ha: diff < 0               Ha: diff ~= 0              Ha: diff > 0
       t =  -0.9523                t =  -0.9523              t =  -0.9523
   P < t =   0.1707          P > |t| =   0.3413          P > t =   0.8293
```

. ttest ghps, by(sample); /* General health perception score: 0-100 */;

Two-sample t test with equal variances

```
------------------------------------------------------------------------------
  Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |     283    67.54417    .9463214    15.91959    65.68142    69.40692
   pilot |     309    70.22654    .8848994    15.55511    68.48532    71.96775
---------+--------------------------------------------------------------------
combined |     592    68.94426    .6483142    15.77417    67.67098    70.21754
---------+--------------------------------------------------------------------
    diff |           -2.682368    1.294278               -5.224319   -.1404158
------------------------------------------------------------------------------
Degrees of freedom: 590
                 Ho: mean(final) - mean(pilot) = diff = 0
     Ha: diff < 0               Ha: diff ~= 0              Ha: diff > 0
       t =  -2.0725                t =  -2.0725              t =  -2.0725
   P < t =   0.0193          P > |t| =   0.0387          P > t =   0.9807
```

. ttest evs, by(sample); /* Energy vitality score: 0-100 */;

Two-sample t test with equal variances

```
------------------------------------------------------------------------------
  Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |     283    62.61484    .9369854    15.76253    60.77047    64.45921
```

```
   pilot |   309   63.33333   .9140595    16.0677   61.53474   65.13192
---------+--------------------------------------------------------------------
combined |   592   62.98986   .6540264   15.91315   61.70537   64.27436
---------+--------------------------------------------------------------------
    diff |        -.7184923   1.310091              -3.291502   1.854518
------------------------------------------------------------------------------
Degrees of freedom: 590
                Ho: mean(final) - mean(pilot) = diff = 0
     Ha: diff < 0           Ha: diff ~= 0           Ha: diff > 0
       t =  -0.5484           t =  -0.5484           t =  -0.5484
   P < t =   0.2918     P > |t| =   0.5836       P > t =   0.7082
```

. ttest sfs, by(sample);   /* Social functioning score: 0-100 */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |   Obs      Mean   Std. Err.  Std. Dev.  [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |   283   74.67609   1.045763   17.59245    72.6176   76.73458
   pilot |   309   76.30349   .8921366   15.68233   74.54803   78.05894
---------+--------------------------------------------------------------------
combined |   592   75.52552   .6834294   16.62856   74.18328   76.86777
---------+--------------------------------------------------------------------
    diff |        -1.627398   1.367698              -4.313547   1.058751
------------------------------------------------------------------------------
Degrees of freedom: 590
                Ho: mean(final) - mean(pilot) = diff = 0
     Ha: diff < 0           Ha: diff ~= 0           Ha: diff > 0
       t =  -1.1899           t =  -1.1899           t =  -1.1899
   P < t =   0.1173     P > |t| =   0.2346       P > t =   0.8827
```

. ttest res, by(sample);   /* Role limitation emotional score: 0-100 */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |   Obs      Mean   Std. Err.  Std. Dev.  [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |   283   76.32509   2.037718   34.27973   72.31402   80.33616
   pilot |   309    81.5534   1.841193   32.36521   77.93049    85.1763
---------+--------------------------------------------------------------------
combined |   592   79.05405   1.371432   33.36838   76.36058   81.74753
---------+--------------------------------------------------------------------
```

```
    diff |   -5.22831   2.739395            -10.60846   .1518424
------------------------------------------------------------------------------
Degrees of freedom: 590
                 Ho: mean(final) - mean(pilot) = diff = 0
     Ha: diff < 0           Ha: diff ~= 0           Ha: diff > 0
       t =  -1.9086           t =  -1.9086           t =  -1.9086
   P < t =   0.0284     P > |t| =   0.0568       P > t =   0.9716
```

. ttest chs, by(sample);   /* Change in health score: 0-100 */;

```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
   final |     283    57.15548    1.329841    22.37139     54.5378    59.77315
   pilot |     309    59.87055    1.291095    22.69539    57.33007    62.41103
---------+--------------------------------------------------------------------
combined |     592    58.57264    .9273294     22.5629    56.75137     60.3939
---------+--------------------------------------------------------------------
    diff |           -2.715073    1.854657               -6.357607    .9274607
------------------------------------------------------------------------------
Degrees of freedom: 590
                 Ho: mean(final) - mean(pilot) = diff = 0
     Ha: diff < 0           Ha: diff ~= 0           Ha: diff > 0
       t =  -1.4639           t =  -1.4639           t =  -1.4639
   P < t =   0.0719     P > |t| =   0.1437       P > t =   0.9281
```

10.3. Non-parametric estimation of WTP using the responses to the follow-up questions

This section is based on Carson *et al.* (2003) and Terawaki (2003), which describe the procedure to estimate the non-parametric Turnbull estimator using the answers to the double-bound dichotomous choice questions. The initial task involves estimating the frequency of each possible combination of responses for all bid values[107]. Table 88, Table 89 and Table 90 present the results in percentages, as proposed in Carson *et al.* (2003).

Table 88: Percentage of responses per type of response – 5-in-1000 immediate risk reduction

Bid	Yes -Yes	Yes - No	No – Yes	No - No	Total
Total sample					
240	56.94	20.83	5.56	16.67	100
600	53.03	15.15	6.06	25.76	100
1,800	54.79	12.33	5.48	27.40	100
2,700	45.83	13.89	9.72	30.56	100
Flag0 = 0					
240	57.41	18.52	5.56	18.52	100
600	44.19	18.60	2.33	34.88	100
1,800	53.85	5.77	3.85	36.54	100
2,700	41.67	8.33	4.17	45.83	100
Flag4 = 0					
240	56.25	21.88	3.13	18.75	100
600	53.45	13.79	6.90	25.86	100
1,800	53.13	12.50	6.25	28.13	100
2,700	49.23	13.85	10.77	26.15	100

Table 89: Percentage of responses per type of response – 1-in-1000 immediate risk reduction

Bid	Yes –Yes	Yes - No	No – Yes	No - No	Total
Total sample					
240	58.33	12.50	12.50	16.67	100
600	37.88	13.64	13.64	34.85	100
1,800	36.99	6.85	12.33	43.84	100
2,700	44.44	9.72	4.17	41.67	100
Flag0 = 0					
240	51.85	14.81	12.96	20.37	100
600	23.26	11.63	16.28	48.84	100
1,800	25.00	1.92	13.46	59.62	100
2,700	35.42	4.17	0.00	60.42	100
Flag4 = 0					
240	56.25	12.50	14.06	17.19	100
600	43.10	10.34	13.79	32.76	100
1,800	40.63	4.69	14.06	40.63	100
2,700	47.69	10.77	4.62	36.92	100

[107] The complete structure and sequence of the bid values used was presented in Table 29.

Table 90: Percentage of responses per type of response – 5-in-1000 risk reduction in the future

Bid	Yes –Yes	Yes - No	No – Yes	No - No	Total
		Total sample			
240	57.78	13.33	11.11	17.78	100
600	51.22	9.76	9.76	29.27	100
1,800	47.62	9.52	2.38	40.48	100
2,700	47.06	7.84	7.84	37.25	100
		Flag0 = 0			
240	54.29	11.43	14.29	20.00	100
600	33.33	8.33	16.67	41.67	100
1,800	41.38	6.90	3.45	48.28	100
2,700	45.95	8.11	8.11	37.84	100
		Flag4 = 0			
240	60.00	12.50	12.50	15.00	100
600	56.76	8.11	8.11	27.03	100
1,800	51.35	10.81	2.70	35.14	100
2,700	50.00	8.33	8.33	33.33	100

Table 91, Table 92 and Table 93 present the results of the Turnbull estimation of the probability that the underlying willingness-to-pay value is greater than the upper bound value of each interval, and the corresponding change in the density function.

Table 91: Turnbull estimation results – 5-in-1000 immediate risk reduction

Interval	Total sample		Flag0 = 0		Flag4 = 0	
	A	B	A	B	A	B
0-120	0.833	0.167	0.815	0.185	0.813	0.188
120-240	0.761	0.072	0.711	0.103	0.762	0.050
240-600	0.659	0.102	0.611	0.101	0.651	0.112
600-1800	0.635	0.024	0.531	0.079	0.647	0.003
1800-2700	0.572	0.063	0.520	0.011	0.581	0.066
2700-3600	0.458	0.114	0.417	0.103	0.492	0.089
3600-infinite	0.000	0.458	0.000	0.417	0.000	0.492

Notes: A = Probability of WTP being greater than upper bound of interval; B = Change in density

Table 92: Turnbull estimation results – 1-in-1000 immediate risk reduction

Interval	Total sample		Flag0 = 0		Flag4 = 0	
	A	B	A	B	A	B
0-120	0.833	0.167	0.796	0.204	0.828	0.172
120-240	0.681	0.152	0.598	0.198	0.680	0.148
240-600	0.555	0.127	0.430	0.168	0.565	0.116
600-1800	0.469	0.085	0.301	0.129	0.508	0.056
1800-2700	0.455	0.014	0.320	-0.019	0.496	0.012
2700-3600	0.444	0.011	0.354	-0.034	0.477	0.019
3600-infinite	0.000	0.444	0.000	0.354	0.000	0.477

Notes: A = Probability of WTP being greater than upper bound of interval; B = Change in density

Table 93: Turnbull estimation results – 5-in-1000 risk reduction in the future

Interval	Total sample		Flag0 = 0		Flag4 = 0	
	A	B	A	B	A	B
0-120	0.822	0.178	0.800	0.200	0.850	0.150
120-240	0.709	0.113	0.627	0.173	0.727	0.123
240-600	0.594	0.116	0.500	0.127	0.632	0.096
600-1800	0.575	0.019	0.500	0.000	0.623	0.009
1800-2700	0.516	0.058	0.485	0.015	0.553	0.070
2700-3600	0.471	0.046	0.459	0.025	0.500	0.053
3600-infinite	0.000	0.471	0.000	0.459	0.000	0.500

Notes: A = Probability of WTP being greater than upper bound of interval; B = Change in density

The change in density of each interval is then multiplied by the lower bound value of each interval and summed-up to produce the non-parametric Turnbull mean value of annual willingness to pay, shown in Table 94.

Table 94: Non-parametric (lower-bound) Turnbull estimation of mean annual willingness to pay (US$ 2003) using the follow-up questions

	5-in-1000 risk reduction			1-in-1000 risk reduction		
	Total sample	Without Flag0 =1	Without Flag4 =1	Total sample	Without Flag0 =1	Without Flag4 =1
Immediate	623.01	554.05	637.05	515.90	379.27	549.88
Future	580.92	529.74	621.13	---	---	---

Estimates are distribution-free and conservative.
US$ 1 = R$ 3.40 during the survey period (March/2003).